The TREND IN ENGINEERING

at the University of Washington

In this issue:

OLIVINE FINES FOR FOUNDRY USE

LATERAL BUCKLING OF SLENDER REINFORCED CONCRETE BEAMS

COMPUTING MACHINES FOR LANGUAGE TRANSLATION

A STUDY OF REACTIONS AT SAND-METAL INTERFACES

SUSPENSION-BRIDGE REPORT COMPLETED

July, 1954

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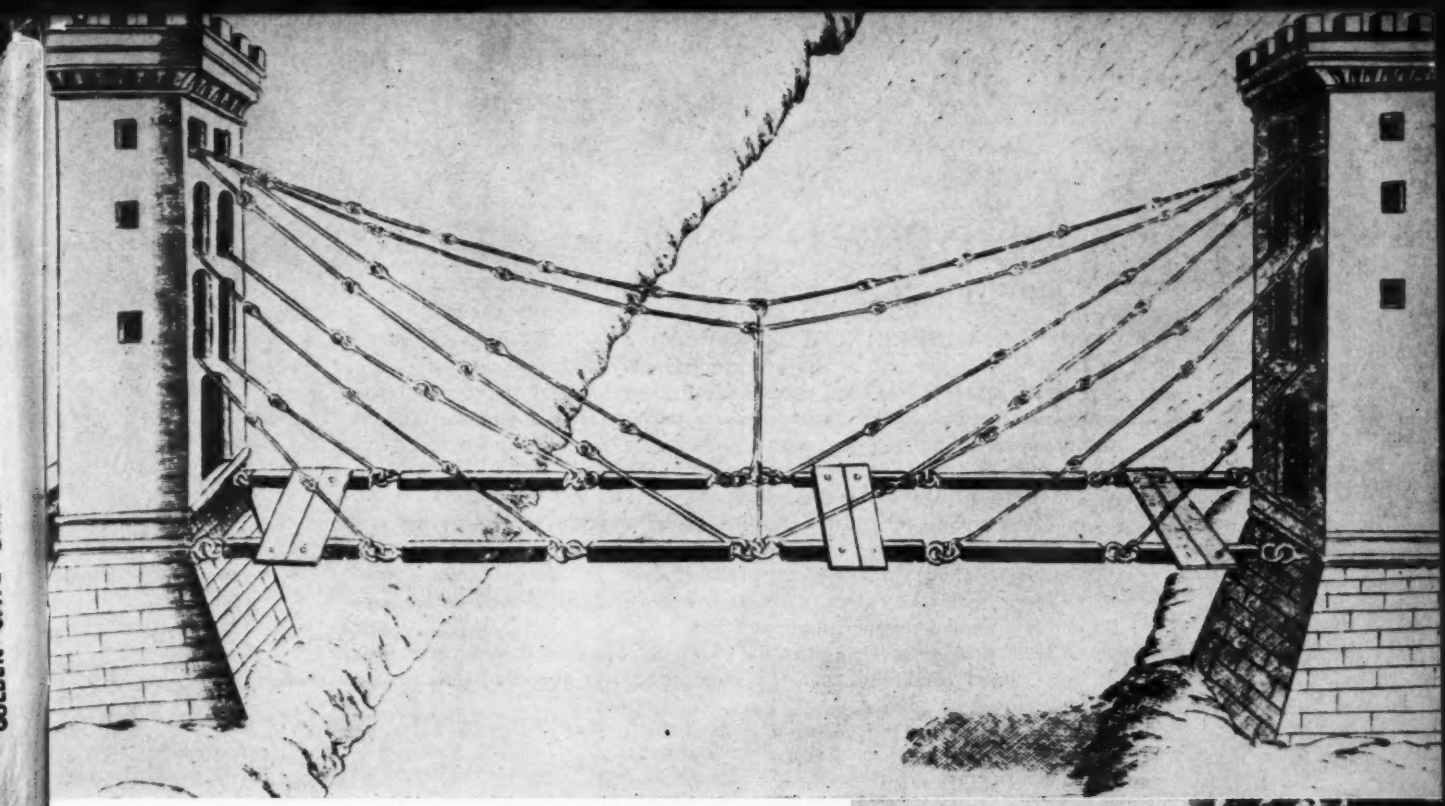
THE ENGINEERING EXPERIMENT STATION

TACOMA NARROWS BRIDGE
BRONX-WHITESTONE BRIDGE
GEORGE WASHINGTON BRIDGE
GOLDEN GATE BRIDGE



ABOUT SUSPENSION BRIDGES

FROM THE DAY THAT A PRECOCIOUS MONKEY initiated jungle tree-travel across tangled lianas, to May 27, 1937, when the Golden Gate Bridge was dedicated, an enormous measure of time, as well as space, has been spanned. Yet, today, the world traveler can still behold many successive stages in the development of the suspension bridge. In parts of Central and South America, in China and India, the most primitive types of "one-rope" and "two-rope" devices are still in use, as well as those involving numerous ropes supporting rough platforms, with extra ropes for handrails.

The Chinese have apparently always been great bridge builders. (In the 13th century, Marco Polo reported 1,200 bridges in the city of Hangchow, alone.)[1] The famous Kuang Hsien suspension bridge, which is more than 700 feet in over-all length with a maximum span of 200 feet, and is 9 feet in width, is carried by 10 bamboo ropes each 6½ inches in diameter, with five similar ropes forming each handrail. (Tests on similar ropes are reported to show 26,000 psi tensile strength.) Capstans, embedded in masonry, are revolved by spars to keep the cables taut. Floor planking is held down by bamboo ropes. The bridge "houses" are masonry.[2]

Rope suspension bridges, sometimes of portable type, were probably in common use in Europe from the early 16th to the 19th century, but contemporary records apparently were concerned only with those constructed for military use.[3]

While early metal chain suspension bridges in China have been traditionally dated to as far back as 200 B.C., the earliest first-hand source is 1667.[3] It is more likely that about the 15th century metal structures began to replace rope bridges on the same sites. One of the most notable iron chain bridges was the Lu Ting, built in 1701, which had a maximum span of 192 feet. Flooring was laid directly on the chains, and windlasses kept the chains tight.[1]

In the western world, the bridge design of Verantius (illustrated), which appeared in his book, *Machinae Novae*, published in

(Continued on page 26)

Above

METAL SUSPENSION BRIDGE DESIGNED BY VERANTIUS (1595) Note eyebars of the bottom chord which are encased in wood to which the plank decking was to be fastened.

Below

ANCIENT TYPE OF CHINESE ROPE SUSPENSION BRIDGE The stone weight in the upper part of the tower prevents the columns from being lifted out of place. The modern photograph suggests it was still in use in recent years.

GEORGE WASHINGTON BRIDGE

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgical, Ceramic Engineering
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. Results of major investigations are published in the form of bulletins and reports. Current research findings from the Station's fellowship projects, as well as accounts of its activities, appear in the quarterly journal, *The Trend in Engineering at the University of Washington*. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

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CONTENTS

About Suspension Bridges 1

Olivine Fines for Foundry Use *William A. Snyder* . . 5

Lateral Buckling of Slender Reinforced Concrete Beams *D. Vasarhelyi, Ismet Turkalp* 8

Computing Machines for Language Translation *T. M. Stout* 11

A Study of Reactions at Sand-Metal Interfaces *E. A. Rowe, R. T. Torgerson* 16

Suspension Bridge Report Completed 22

Michigan Bridge Model to Be Tested 22

Engineering Teachers "Retire" to Active Professional Life 23

New Text on Electric Fields by Rogers *(Review) Ronald Geballe* 24

Engineering Research Dividends 25
Design and Use of Ejector and Draft Tube for the Ozonation of Water *D. F. Hogan*

Notes and Comments 28
Engineers in the News
New Reprints

ERL Transferred to School of Medicine 28

FRONT PAGE

Illustrations: "Bridge by Verantius" from W. B. Parsons, *Engineers and Engineering in the Renaissance,* Williams & Wilkins, 1939. "Chinese Bridge" from Fugl-Meyer, "Bridge Building, an Art of Ancient China," *Civ. Eng.,* Vol. 4, No. 2 (Feb. 1934).

Clockwise from lower left: FIG. 1. Professor Snyder with the device for classifying olivine sand. FIG. 2. Aluminum alloy castings produced in synthetic olivine aggregate molding sand. FIG. 3. Aluminum alloy casting made in oil-bonded olivine molding sand. FIG. 5. Steel casting produced in silica sand containing olivine fines. FIG. 4. Iron casting made in olivine fines bonded by oil and a fusible bond .

OLIVINE FINES FOR FOUNDRY USE

WILLIAM A. SNYDER

Assistant Professor of Mechanical Engineering

W. A. Snyder

Olivine Sand

In the fall of 1950, the Shops Division of the Mechanical Engineering Department started an extensive investigation into the use of olivine sand as a refractory aggregate for foundry usages. Under the guidance of Prof. Gilbert S. Schaller, this research project has tested olivine aggregate in all processes requiring refractory sands employed in commercial foundries. This mineral, found in great abundance in the state of Washington, has proved to be an excellent foundry material. The high fusion point, uniform thermal expansion, resistance to heat shock, and high density, are technical points of superiority over silica, the refractory sand commonly used by American foundries. Medical research, which indicates that olivine dust is nontoxic and exhibits only a foreign body reaction in the lung, is considered to be a point of great social significance.

The most important use of refractory sands in the foundry is as the aggregate of synthetic molding sands for heavy iron and steel casting. The grain-size required for this purpose will vary, depending upon the mechanical properties required of the molding sand for its particular use. The useful grains, however, are generally considered to be those in the rather limited size range between 30- and 150-mesh. Excessive quantities of larger or smaller materials are generally considered to be detrimental. Sands commonly used for this purpose in foundries today were formed by nature; they have been classified by the action of wind or water and deposited in layers of fairly uniform grain-size. These materials are selectively mined, leaving the undesired fractions in the earth. Olivine weathers more readily than silica and is not found in suitable sand deposits; therefore olivine sand must be manufactured from the massive mineral. Since the manufacture of sand in the desired range of grain sizes involves the production of large amounts of fine materials, developing uses for olivine fines is an economic necessity, if aggregate for synthetic molding sand is to be made available at competitive prices.

Origin of Olivine Fines

Investigation of the most suitable method of manufacturing olivine sand is not a part of our research program; however, since there is no commercial source of this material on the west coast it has been necessary for the University of Washington to prepare its own sand from the massive material. At the present time, processing starts with material that has been reduced by primary crushing wherein no aggregate is larger than ½ in. in its major dimension. This material is fed through a small ball mill and then screened to minus 16 mesh; oversize grains are recirculated through the ball mill. The material that passes the screen is then passed through a dry classifying device (Fig. 1) designed to separate the sand into useful fractions. The results of classifying may be controlled to a degree by adjustments of the apparatus. Table I shows a typical separation into three grades of sand.

One-third of the classified sand is in the fraction designated as fines. Improved crushing procedures with modern equipment would reduce the percentage of fines, but even under the best conditions, they will make up a substantial portion of the total. Several methods of using the fines have been successfully investigated.

TABLE I

SCREEN ANALYSIS OF CLASSIFIED OLIVINE

U. S. SCREEN No.	PERCENTAGE RETAINED		
	Coarse	Medium	Fine
6	–	–	–
12	–	–	–
20	24.5	1.0	–
30	38.4	3.1	–
40	24.2	9.2	+
50	9.1	21.2	5.5
70	2.1	29.2	7.8
100	T	22.0	13.6
140	–	10.6	17.0
200	–	2.7	16.3
270	–	T	19.4
pan	–	1.1	22.0
Total	98.3	100.1	101.6

Synthetic Non-Ferrous Molding Sand

Natural molding sands are widely used for preparing molds for the low melting point, non-ferrous alloys. These sands, as found in the earth, contain a suitable bonding clay. They are carefully mined and are used in the foundry without special treatment or additions. Natural molding sands are widely distributed; however, they vary in quality and usefulness. Some pits with reputations of excellence ship their products great distances, and often the freight charge is several times the cost of the sand.

In recent years some non-ferrous foundries have converted their operation to "synthetic" molding sand. This material is mixed in the foundry from sand, either natural or manufactured, and selected bonding clays. The fine grain-size required for this use, 100- to 270-mesh, is not commonly found in the clay-free condition. The user is limited in his selection of aggregate to that which may be found in natural deposits. Manufactured sand is not popular for this use at the present time; however, it affords two worthwhile advantages over natural aggregate. Manufactured sand offers a greater selection of grain-size and distribution; of equal importance is the fact that, since this material is produced to specification, it can be accurately duplicated at any future time. A natural sand purchased from a certain deposit today may be considerably different from material of that same deposit fifteen years ago.

Olivine fines have been used for four years as the aggregate for synthetic non-ferrous molding sand at the University of Washington. Aluminum alloy castings made in this sand are shown in Fig. 2. The first of these molding sands were prepared by mixing 96 parts of olivine fines with four parts of southern bentonite. This mixture when tempered with 4½ per cent of water gave a molding material with satisfactory mechanical properties for use in producing brass- and aluminum-alloy castings. This sand produced excellent surfaces and had a life or durability superior to most natural sands. At the present time, synthetic non-ferrous molding sand is prepared from 93 parts of olivine fines, 6 parts of air-floated fire clay, and one part of western bentonite. This exhibits better durability than the original mixture, providing more stable mechanical properties and showing less tendency to form "clay balls."

This sand could be further improved by elimination of about half of the grains that are small enough to pass through a 270-mesh screen. This can be done by redesigning the classifying apparatus to separate the fines into two fractions; in fact, this step was accomplished by the first experimental dry classifier.

Molding Sands Bonded by Surface Tension

These materials are an original development of the University of Washington and are a direct result of a program designed to find uses for olivine fines. Unlike all other molding sands, these materials are bonded only by the surface tensions of fluids or semi-fluids. The strength of these sands will disappear when the bonding fluid is evaporated or destroyed. The use of molds made from these materials is limited to producing small castings or castings with thin sections. A skin of solidified metal must be formed before the bond at the mold-metal interface is evaporated.

The green strength of these molding sands depends on the grain-size of the aggregate, the surface tension of the bonding fluid, and the amount of the bonding fluid. Surface tension provides very little strength to a coarse uniform aggregate. However, as the grain-size decreases and the number of points of contact increases, sands with usable strengths are obtained.

Sand bonded with water, a fluid of low viscosity and high surface tension, is much stronger than a similar aggregate bonded with 600W oil, an extremely viscous gear lubricant. Sand bonded with cup grease is weaker than either the water-bonded or oil-bonded sands. Sand bonded with water and oil is stronger than sand bonded with an equivalent amount of water only. For any given bonding fluid, experiments indicate that within working limits the strength is increased with an increased percentage of bond. Research has revealed that any given aggregate requires a certain volume of bond for optimum results. Olivine fines gave the best results when 10 lb of sand was mixed with 200 cc of bond, regardless of whether that bond was water, oil, or grease.

Since conventional molding-sand bonding materials resist compacting, it is difficult or impossible to ram ordinary molding sands to maximum density. The use of extremely fine aggregate with clay bonds promotes the formation of "clay balls" which will cause a rough casting, even though a fine sand is employed. Surface-tension bonds tend to draw the sand grains into a compact orientation whereby maximum density is easily obtained; further, it is not possible for the sand to "ball" when a liquid bond is used. As a result, castings of unsurpassed surface smoothness can be produced with surface-tension bonded sands.

Figure 3 shows an aluminum-alloy casting made in a mold of olivine fines bonded with oil. This casting is 3 in. in diameter and ½ in. thick. Similar aluminum castings were made in sands bonded with water and grease. This identical casting was made successfully from iron and brass when water was the

bonding agent, but could not be produced with the other bonds which were destroyed before pouring was completed.

Sands with Surface Tension and Fusible Bonds

These materials are also an original development of the University of Washington. The green strength of these sands is provided by a liquid bond. The sand also contains a finely pulverized material which will fuse and create a secondary bonding action before the liquid bond is destroyed. This will permit large castings to be made in sand that will give the smoothness and accuracy characteristic of the liquid-bonded sands.

When this type of molding material is used to produce large castings, it is used only as a thin facing layer at the mold-metal interface. This facing sand, never more than ½ in. thick, is backed up by clay-bonded molding sand of high permeability.

Figure 4 shows a 25-lb iron casting produced in a mold faced with olivine fines containing 3½ per cent P.S. 200 fuel oil and 5 per cent of a pulverized thermosetting resin. This casting has received no cleaning. The smooth surface was produced by olivine fines; the rough surface was produced by the backing sand. This casting and gating system was designed to test critically the sands under discussion. The casting itself is of no significance, except that by varying its size the amount of metal poured through the gating system is varied. The gate is designed to cause sand to wash or be displaced if the bond becomes too weak during pouring. The sand being tested is used as a facing material only on the gating system.

The oil-plastic bonded sand described can be stored for long periods without changing its properties. It can be mixed and packaged and will be ready for use without further treatment at any future date.

Many combinations of liquid and fusible bonds remain to be investigated, and the research data developed at this time have not been published. A seemingly endless amount of interesting development work remains to be done in this field.

Olivine Fines as a Substitute for Silica Flour

In the synthetic molding sand practice used by steel foundries at the present time, the grain-size of the aggregate cannot be varied to give the desired result. One or two standard aggregates are used for all mixtures. Finely pulverized silica flour may be added to these aggregates to give the effect of using a finer sand. Silica flour, which is generally ground so that 90 per cent of the material will pass through a 200-mesh screen, is frequently used in synthetic molding sands in amounts up to 15 per cent of the total aggregate weight.

Silica sand itself is not a health hazard, but the fine air-borne silica particles that result from the breakdown of silica sand, and the silica flour used in foundries, are considered to be potential hazards. It is desirable to eliminate silica flour from foundry processes if a suitable substitute can be found.

Casual examination of theory indicates that olivine fines could not be satisfactorily used in silica aggregate since the two materials will react at elevated temperatures to form products that will fuse at temperatures lower than the pouring temperature of steel. Time is a factor in these reactions, however, and it is possible that the casting would solidify before the reactions were complete.

Professor Schaller and the author have recently completed experiments* in which olivine fines were used to replace silica flour in silica aggregates. Test castings in steel of 5-in. thickness were successfully poured with no more indication of sintering or fusing than was shown on control molds made with silica flour. Figure 5 shows a test casting made with synthetic molding sand using silica aggregate and olivine fines.

Mold and Core Wash

Washes are made from finely divided refractory particles held in water suspension. Applied to mold or core surfaces by either dipping, brushing, or spraying, their function is to provide a smooth, dense surface that will prevent metal from penetrating into sands of high permeability. Silica flour and zirconite flour are commonly used to prepare mold and core washes for use in the steel foundry. No extensive research has been pursued in the use of olivine for this purpose; however, mold washes made from olivine fines have been used satisfactorily to produce steel castings.

For this use it is desirable that most of the refractory aggregate be finer than 200-mesh. To provide a satisfactory material for mold or core wash, would necessitate further separation of the olivine fines. Such separation would leave an improved aggregate for non-ferrous synthetic molding sand.

Conclusions

Work in the development of foundry uses for olivine fines originated from a desire to market all of the products of preparation. Some of this research, however, has opened entirely new areas of interest for the foundry man. These investigations, now in the preliminary stages, may, with further development, provide new concepts of the finish and accuracy

(Continued on page 32)

* All experimental work was conducted at the Washington Iron Works of Seattle, and was made possible by the generous cooperation of this company with the University of Washington.

LATERAL BUCKLING OF SLENDER REINFORCED CONCRETE BEAMS

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Graduate Student in Civil Engineering

D. Vasarhelyi

Few engineers have anticipated having ever to face the problem of lateral buckling in a reinforced concrete beam. Even references in the technical literature are hard to find on the subject. In fact, recent search has failed to locate any reference to actual lateral buckling of a reinforced concrete beam. A good look at the span-to-width (l/b) ratio of past and present reinforced beams has apparently convinced everyone that, in the conventional structure, there *is* no chance for lateral buckling to occur.

It is hard to believe that this reassuring situation is with us for good. The constantly decreasing dimensions in modern design, especially in prestressed elements, warn us that we may soon, for the first time, have to face the problem of lateral buckling of reinforced concrete flexural elements.

The experiment we are discussing here had a very modest objective: to produce lateral buckling of a reinforced concrete beam, thus proving tangibly the existence of the problem and giving some indication of experimental conditions under which it might occur.

Synopsis

Three reinforced concrete specimens of a span-to-width (l/b) ratio of 36, and with three different types of reinforcement, were tested in bending. In all three tests lateral deflection was distinctly measurable. The fractured surface in all three cases was characteristic of a combined action of bending and torsion. The possibility of lateral buckling of a reinforced concrete beam was thus demonstrated, and it could be concluded that an expansion of our present knowledge of the torsional rigidity of reinforced concrete sections will be necessary for an efficient analysis of this type of problem.

Discussion

The test arrangement and the dimensions of the specimen are shown in Fig. 1. The concrete was one of 1 : 2 : 3 ratio, with a water-cement ratio of 0.55. The gravel passed the ⅜-in. sieve; thus the aggregate was scaled down in order to conform with the model character of the specimens. Timber forms were used, and the beams were cast in a horizontal position. They were removed from the forms at the age of two days and kept in a curing room (75° F, 100 per cent humidity) until the age of 28 days, when they were tested. The simultaneously prepared and similarly cured standard cylinders gave the following results (average of two) at 28 days:

Spec. No. 1: 4160 psi
Spec. No. 2: 4020 psi
Spec. No. 3: 4300 psi
Average: 4160 psi

The reinforcements were ⅜-in. deformed bars and ¼-in. stirrups. The properties of the ⅜-in. bars (results of tests) were as follows:

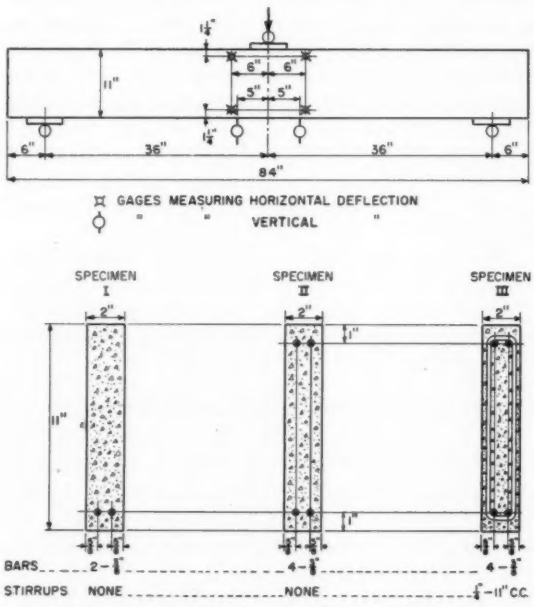


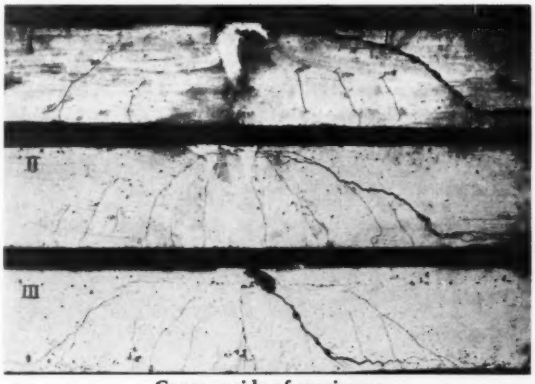
FIG. 1. TESTING ARRANGEMENT OF SPECIMENS AND THEIR CROSS SECTIONS

* Mr. Turkalp received his degree of M.S. in Civil Engineering in 1953, and is now in Turkey.

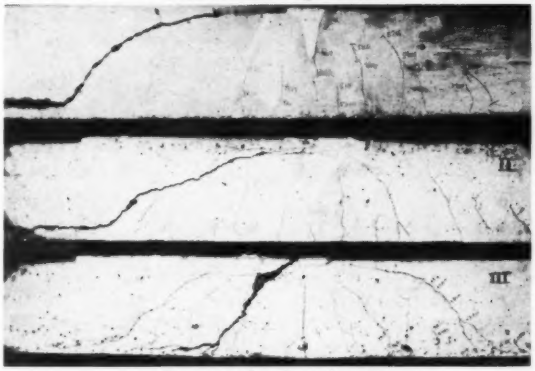
Yield point: 41,500 psi
Ultimate strength: 52,000 psi

The beams, of 2-in. by 11-in. cross section (Fig. 1), were supported on rollers 72 in. center-to-center, giving a span-to-width (l/b) ratio of 36. The reinforcement was such that a failure by yielding of the bars should have occurred. They were loaded by a single load applied at the mid-span. Vertical deflections were measured at two points located 5 in. on each side of the mid-span. The average of these two values is referred to as "vertical deflection." Lateral deflections were measured at four points: two at 6 in. on each side of the mid-span, and 1¼ in. from the lower edge; and the other two at the same distance from the mid-span and 1¼ in. from the upper edge. The averages of the readings at the lower and upper edge are referred to as "lateral deflection, lower edge," and "lateral deflection, upper edge," respectively. All deflections were measured by dial gages reading in 0.001 in.

The load was applied in 200-lb increments, and readings of the gages were taken. The cracks were marked as they appeared and progressed, as shown in Fig. 2.



Concave side of specimens



Convex side of specimens

FIG. 2. CRACKS IN BEAMS AFTER FAILURE

The loads at which the first crack appeared, and the ultimate loads are as follows:

Spec.	*First Crack*	*Ultimate Load*
No. 1	2200 lb	6000 lb
No. 2	2400 lb	5000 lb
No. 3	2000 lb	7000 lb

The vertical deflection values are shown on Fig. 3. The plots do not reveal any irregularities. The effect of the two bars on the compression side may be the cause of curves II and III overlapping, while curve I deviates from them.

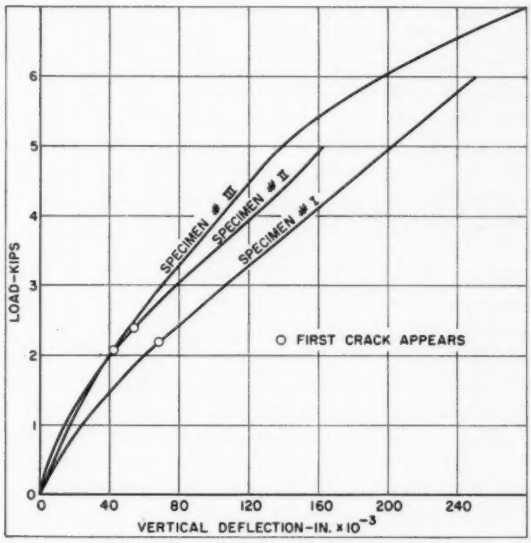


FIG. 3. VERTICAL DEFLECTION OF BEAMS

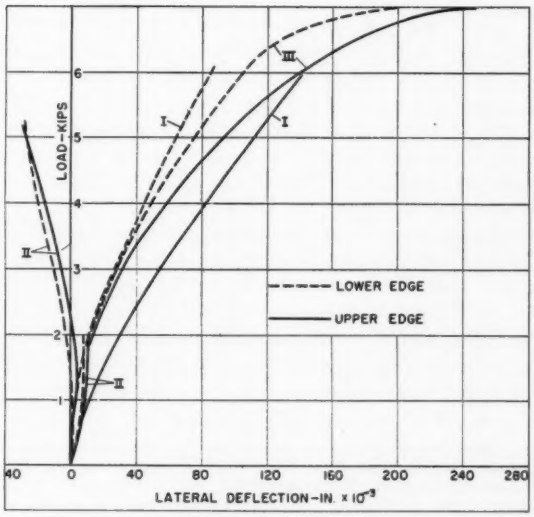


FIG. 4. LATERAL DEFLECTION OF BEAMS

The lateral deflections, both for the upper and the lower edge of the beam, are shown on Fig. 4. Significant is the fact that the values of the lateral deflection are comparable to the values of the vertical deflections at the same loads. The sudden change of the slope of curve III at 6,000 lb indicates the occurrence of final instability, which could not be observed on I because of the sudden fracture. Specimen II changed the direction of its lateral buckling after an unloading-reloading cycle; thus curve II does not follow the same pattern but it reveals the same general character.

Figure 2 shows the pattern of the cracks and their progress. The type of final fracture could be characteristic of beams with insufficient shear reinforcement. However, in the case of Specimen III, this is not true. In fact this beam started to fail by the opening up of a crack at the center of the span due to the yielding of the tensile reinforcement, and then switched to the diagonal type of fracture, similar to the fracture of the two other specimens.

The fractured surface definitely revealed the fact that a twist about the longitudinal axis of the beam contributed to the development of the fracture. This may be seen on Fig. 5, which shows the edge of the fracture on the convex and on the concave sides of the beam (as determined by the lateral deflections).

Conclusion

Both the observed lateral deflections and the type of fracture indicate that lateral buckling occurred in all three cases of slender reinforced concrete beams. This was the apparently prevailing cause of failure of Specimen No. III, which otherwise would not have failed in a manner characteristic of beams weak in diagonal tension.

The cycling of the loads (not illustrated) proved that at low loads the beam behaved elastically both in its vertical and in its lateral deflection.

The lateral as well as the vertical deflection did not vary significantly with the type of reinforcement. The types of reinforcement used in the specimens apparently did not change, by any significant amount, the torsional rigidity of the cross section.

The present test demonstrates that lateral buckling of reinforced concrete members occurs as soon as their dimensions reach a sufficiently large l/b ratio. In view of the very sparse literature both of lateral buckling and of torsional rigidity of reinforced concrete members, a more extensive investigation would have definite merits.

Acknowledgment

This investigation was carried out as a graduate research project in the Structural Research Laboratory of the Department of Civil Engineering, of which Professor R. B. Van Horn is head. The advice and encouragement of Professors F. B. Farquharson and R. A. Hechtman was greatly appreciated.

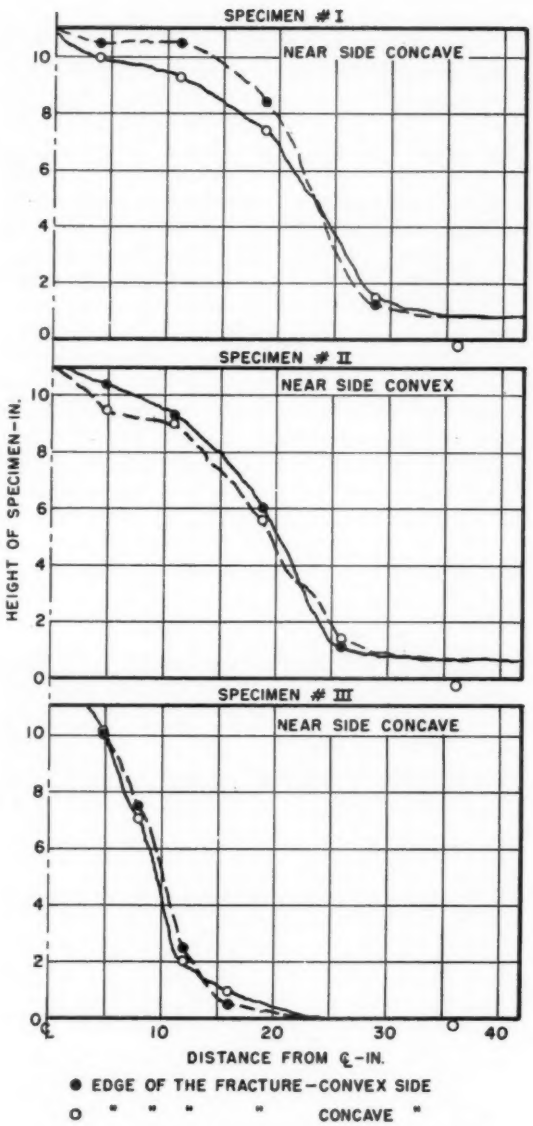


Fig. 5. Fractures on Concave and Convex Sides of Specimens

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Computing Machines for Language Translation

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The computer age is upon us! Just as the steam engine and electric motor have relieved men's muscles of onerous physical labor, so computing machines are relieving men's minds of tiresome mental tasks. In many scientific and engineering problems, modern computing machines have reduced the time required for complex mathematical calculations from months to days, and from hours to seconds. Similar machines are being used to perform repetitive business operations, such as recording payments on insurance policies; to compile statistical data; to keep track of airline ticket sales and reservations; and to control large machine tools, such as milling machines and punch presses. To educate their operators and to amaze the public, such machines have even been asked to play games, such as checkers and chess, or to compose music.

It is not surprising, then, that serious consideration is being given to the use of electronic computers or similar machines to translate written material from one language to another. Efficient manpower requires full use of existing knowledge, whatever its source, and the volume of scientific material in all languages is growing rapidly. Considerable political and military value also lies in having immediate access to large quantities of current material in foreign language newspapers and periodicals. International peace and understanding, in particular, depends on the free exchange of ideas between the peoples of the world.

The supply of skilled translators is limited and unlikely to increase. For scientific material, the translator should be at home in two languages and *in the particular scientific field.* For general material, a translator with a native's command of the subtleties and nuances of the foreign language is desirable, in order not to lose delicate shades of meaning. Since expert translators are not available and cannot be trained in sufficient quantity, and English is unlikely to be adopted as an universal language, use of high-speed electronic computers, for at least part of the translation task, is an obvious answer.

Research on the problems of machine translation has been going on for several years in this country and abroad.[1] Pioneers in this field include Dr. A. D. Booth of the University of London,[2] Dr. Yehoshua Bar-Hillel, formerly of the Massachusetts Institute of Technology,[3] and Dr. Erwin Reifler of the Far Eastern Department of the University of Washington.[4] The latest and best publicized experiment in this new field was conducted at the IBM laboratories in New York on January 7, 1954, under the general supervision of Dr. Leon Dostert and his associates from Georgetown University.[5]

These people admit that the translating machine will not be a substitute for a skilled human translator and do not expect polished translations from a machine. In fact, they point out themselves that a machine translation of modern poetry, for example, cannot be more and will probably be less intelligible than the original. On the other hand, they maintain that the machine would perform a useful function in doing bulk translation of general and scientific material. The output of the machine would be scanned by potential users to determine the importance of the subject matter and then, if necessary, checked and polished by a human editor. Small-scale experiments have already demonstrated the feasibility of translation by mechanical means.

Research to date has been concerned primarily with the complicated linguistic problems involved in mechanical translation, since the engineers can probably build the necessary equipment. This article is intended to suggest some of the linguistic problems to the engineer and to explain some of the engineering ideas for the amateur or professional linguist. The reader is cautioned that the procedures and equipment described are not necessarily the best or most recent, and that considerable development must be done before an actual mechanical translator is built and put into operation.

General Approach: The Language Problem

Present proposals for a mechanical translator involve, in rough terms, constructing a machine which carries out automatically the process that the human translator is imagined to use in converting a sentence from one language (the *source* language) into a new language (the *target* language). This process is assumed to consist of (1) transferring the material

from the printed page to the brain (reading); (2) searching a dictionary to establish the meaning or meanings of each word in the original text; (3) selecting the correct meaning from the possible alternatives; (4) rearranging and refining the results to fit the requirements of the target language; and (5) recording of the results in written or other form for future use. The general procedure may be illustrated by an example.

Suppose the translator is faced with the German sentence:

Er fand die Aufgabe zu schwer,

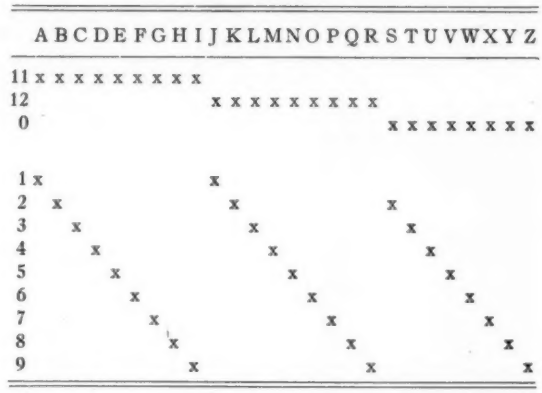
which may be translated, "He found the task too difficult." A German-English dictionary gives the following meanings for the individual words:

Er—he
fand (from *finden*)—found; thought, considered
die—the (article); that, this, he, she, it (dem. pronoun); who, which, that (rel. pronoun)
Aufgabe—task, duty; lesson, exercise; asking (of riddle); posting (of letter); registration (of luggage); giving up, shutting down (of business)
zu—to, at, in, on (preposition); too (adverb)
schwer—heavy; oppressive; clumsy; difficult; grave (illness); indigestible (food); strong (cigar)

Er can be translated only by "he." Although *finden* generally means "to find" in the sense of "to discover," it also has the figurative meaning, "to think" or "to consider." English "find" also shares these meanings and no great harm will be done if *finden* is always translated as "find." The presence of a noun following *die,* indicated by the capital letter or by a dictionary entry opposite *Aufgabe,* makes its translation "the." The translation of *Aufgabe* may be taken as "task" in all cases, since this meaning is general enough to include all of the other, specialized meanings; the nature of the task should be clear from the context. *Zu* is translated as "too" because of the following adjective, which presents the toughest problem in the sentence. The choice in this case evidently depends on the feeling that a task can be difficult, but not heavy, clumsy, grave, indigestible, or strong.

As this example suggests, a word which has only one meaning (or can arbitrarily be assigned only one meaning) will present no problems. Any word with several meanings, however, will cause considerable trouble. The selection of a particular meaning is sometimes based on grammatical considerations, sometimes on the presence of other words or types of words, and sometimes on the nature of the subject matter. In addition to the ability to read and write and search a dictionary, the machine—like the human translator—must be able to discern grammatical distinctions and the occurrence of words which determine the meanings of associated words.

TABLE I
ALPHABET CODING USED IN IBM PUNCHED CARD EQUIPMENT



Coding

At the present stage of development, it is assumed that the translating machine will work only with printed material. In addition to some obvious engineering advantages, this approach has the linguistic advantage that the written language is more distinctive than the spoken language. In English, for instance, the homonyms, not-knot, pair-pear-pare, and numerous other groups of words are easily distinguished by their spelling. The number of words with the same spelling and different pronunciations, such as lead-lead and bow-bow, is much smaller.

Since most computers are designed to work with numbers, the incoming text must be converted from the written alphabet into a numerical form acceptable to the machine. Several different coding schemes are available for this purpose. One obvious procedure is simply to number the letters, using either two-digit decimal numbers or five-digit binary numbers. Coded in this manner, A-B-C-D . . . would become 01-02-03-04 . . ., or 00001-00010-00011-00100. . . .

Other codes are commonly used in standard equipment which might be incorporated in a translating machine. Machines available from IBM use the code given in Table I, in which each letter is represented by two holes punched in a column of a standard punched card; the upper hole is called a zone punch and the other is a digit punch. Standard teletype-writers use the Baudot code given in Table II, which employs five pulse positions in a manner similar to the binary code (plus a sixth pulse for timing).

Binary or teletype coding requires more digits for each letter than the decimal or IBM coding and might appear to require considerably more space. On the other hand, these codes employ only two symbols (0 and 1, pulse and no pulse) for each digit. The physical elements in the computer can therefore be

TABLE II

STANDARD BAUDOT TELETYPE CODE

LETTER	PULSE 1	2	3	4	5	LETTER	PULSE 1	2	3	4	5
A	X	X				N			X	X	
B	X			X	X	O				X	X
C		X	X	X		P		X	X		X
D	X			X		Q	X	X	X		X
E	X					R		X		X	
F	X		X	X		S	X		X		
G		X		X	X	T					X
H			X		X	U	X	X	X		
I		X	X			V		X	X	X	X
J	X	X		X		W	X	X			X
K	X	X	X	X		X	X		X	X	X
L		X			X	Y	X		X		X
M			X	X	X	Z	X				X

simple two-state devices, such as a switch or relay whose contacts are either closed or not closed, a vacuum tube which does or does not carry current, a magnetic core which is magnetized or not, and so forth. Since it is easy to determine which state exists, reliable operation is obtained without any accurate measurements or precision components.

Input and Output Devices

A number of standard devices are available for coding the incoming text for insertion into the machine and, after the translation process is completed, for decoding and printing the translation in the target language. Teletypewriters, operated by typists with no knowledge of either language, could be used to supply electrical signals directly to the translating machine or to prepare punched paper tape for later use. Similar machines can be used to type the final output of the translator.

Input devices now available are relatively slow, so that faster means of supplying material to the translating machine would be essential. An electronic reading device, capable of working directly from the original printed text, has recently been announced.[6] Faster output devices will also be required to maintain over-all balance.

Storage

The dictionary needed in a mechanical translating machine might be stored on a magnetic drum such as the one shown in Fig. 1. This type of storage, in which information is stored by magnetizing small areas on the surface of a revolving cylinder, is widely used in arithmetic computers and has a number of

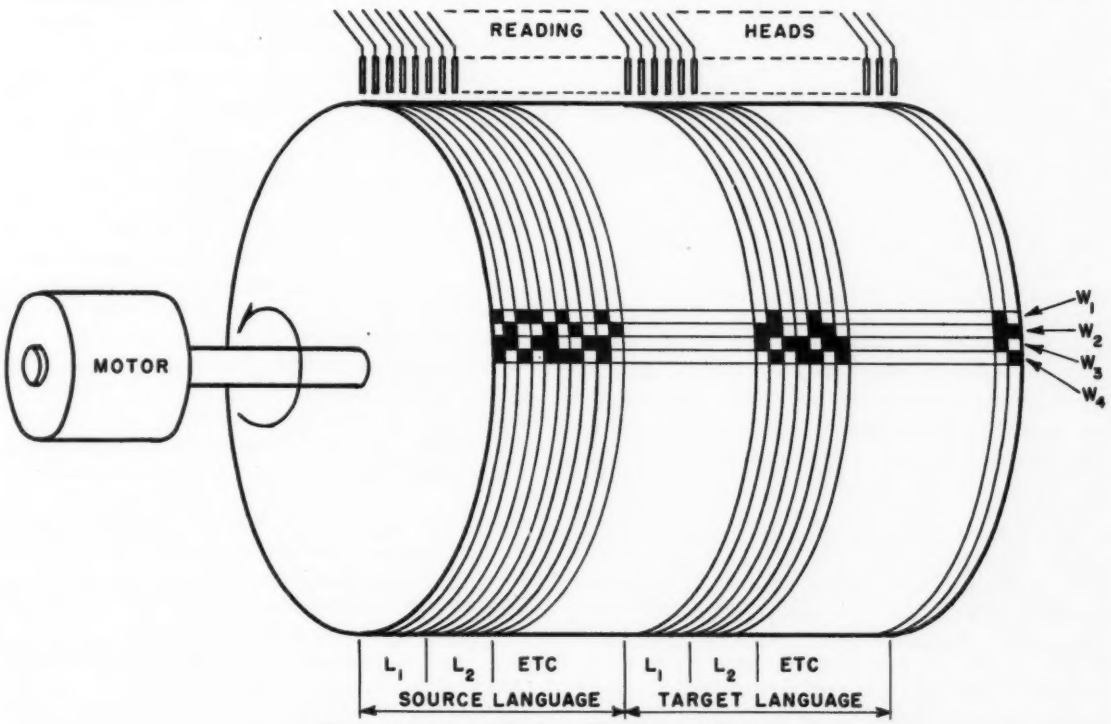


FIG. 1. MAGNETIC DRUM FOR DICTIONARY STORAGE

Words (W_1, W_2, etc.) are stored along the length of the drum, and each letter (L_1, L_2, etc.) requires five tracks around the drum.

desirable properties: a large ratio of information to volume, lower access time, permanence, and simplicity.

Individual words are stored along the length of the drum, (each letter being represented by a group of five magnetized or unmagnetized spots), and pass the reading heads once in each revolution of the drum. Words in the source language are stored at one end of the drum, and their equivalents in the target language at the other end. If the drum is rotated at 2,400 rpm, or 40 rps, each word is available in not more than 25 milliseconds. Following standard practice, 80 spots per inch can be placed around the circumference of the drum and 8 tracks per inch along the length of the drum. Allowing 10 letters or 50 tracks per word in both halves of the dictionary, a drum 12.5 inches long and 12 inches in diameter would hold approximately 3,000 words and their translations.

In order to reduce the average time spent in searching the dictionary, certain common words might be stored several times on the same drum. The 850-word vocabulary of Basic English could be stored three times on a single drum, so that any particular word is available in a third of a revolution or less (not over 8 milliseconds).

To provide an adequate vocabulary for satisfactory translation, several such drums would be required. By searching all drums simultaneously, as explained below, any word in the dictionary could be found in the time required for one drum revolution. At approximately one cubic foot per drum, exclusive of the associated circuits, the space required for a vocabulary of 100,000 words or so becomes rather large. A number of tricks are available, however, for reducing the size of the mechanical dictionary.

If we are concerned with translation into English, as seems probable, many words in the source language text will not require translation. English has borrowed extensively from other languages and many foreign words are immediately recognizable by the English reader. A glance at a German dictionary, for example, reveals such words as *deck, despot, diplomat,* and *dock,* which are identical with the English forms; we also find *demagog, demokrat, direkt, distanz,* and *doktor* which differ slightly in spelling but would present no real difficulties to the reader. The translation process can be by-passed for such words, and the original source word printed directly in the output. This approach must be used with caution, since the two languages may not share all the meanings and connotations of a given word, but it does offer hope for tremendously reducing the size of the mechanical dictionary.

Compound words are rather common in German and can, in fact, be invented at will by writers and

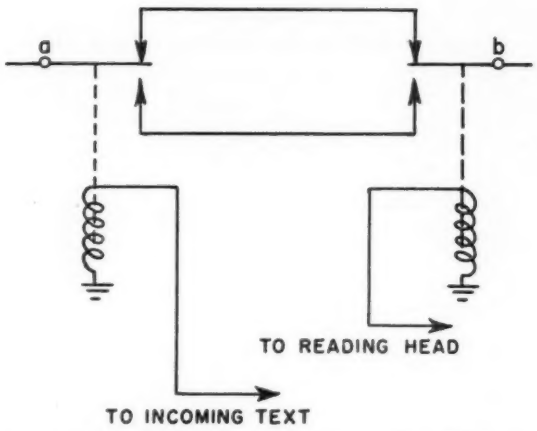


FIG. 2. RELAY CIRCUIT FOR CHECKING ONE PULSE OF INCOMING TEXT WITH ONE TRACK ON DICTIONARY

speakers. If the meaning of a compound is clear from the meanings of its constituents (as is likely for all except old well-established compounds, which will be entered as distinct words), the dictionary can be searched for each constituent separately, and the respective translations compounded on the output side.

Endings, used extensively in other languages to convey grammatical information such as tense and number, can be treated in similar fashion to effect a further reduction in the size of the dictionary. Each word might be regarded as a compound built from a stem, common to all forms of the particular word, and an ending, which may be shared with other words. The dictionary may then be split into a large stem section and a small ending section. A useful by-product of this procedure is the grammatical information made available by the identification of an ending; this may be used in the elimination of impossible translations, as discussed hereafter.

The techniques used in the dissection of compounds will be valuable in still another way. If a word has more letters than are permitted by the physical size of the dictionary (ten letters in the example above), it can be split into two parts which separately signify nothing. *Beratschlagen,* for example, might be split into *beratsc* and *hlagen,* with parts of the translation stored opposite each half. Dictionary space is used more efficiently in this manner, but the processing time may be increased excessively.

Splitting words in order to determine parts of a compound, or stems and endings, is fraught with difficulties which must be explored by linguists. The engineering techniques for carrying out these operations have been devised, but are too involved to discuss here.

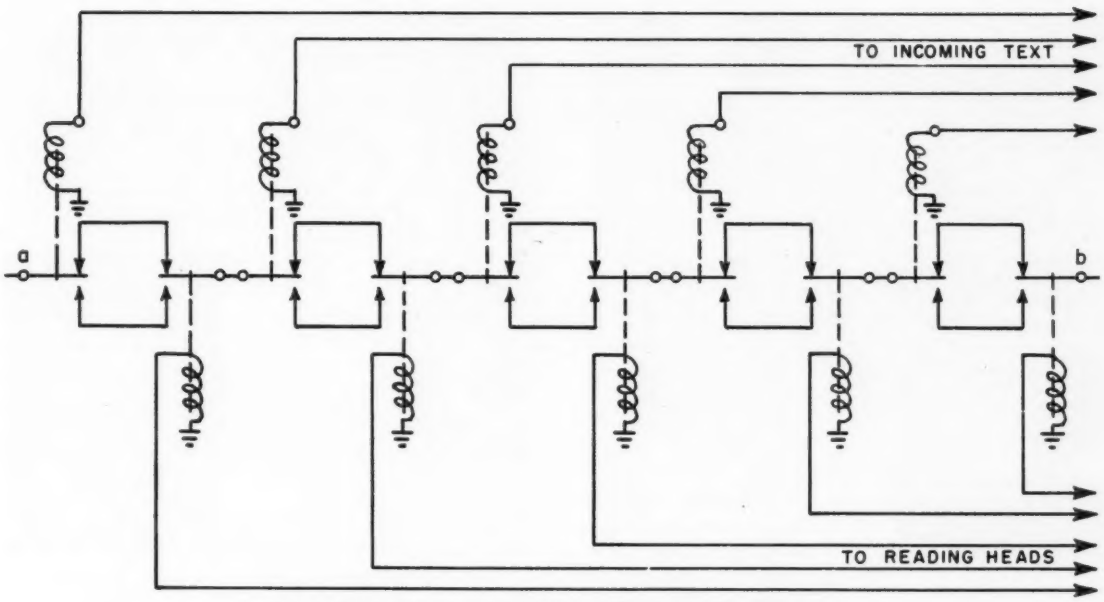


FIG. 3. COMBINATION OF RELAYS FOR CHECKING ONE LETTER

Dictionary Search

In making a mechanical translation, the first step is a comparison of each word of the incoming text with the entire dictionary. If any word is not found in the dictionary in its original form, the dissection scheme for endings and compounds can be tried; if this fails, the word can be printed through without alteration.

Several methods are available for making this comparison; an impractical but easily understood system is shown in Fig. 2. This system requires two single-pole double-throw relays for each pulse position: one relay operated by the incoming text and the other relay operated by pulses from the reading heads on the magnetic drum. The path between points "a" and "b" is closed only when both relays are either energized (pulses present in both incoming word and dictionary) or not energized (spaces present in both places). The occurrence of a closed path, therefore, indicates that the particular pulse position is identical in both the incoming word and the dictionary.

Entire letters, coded as a group of five pulses or spaces, can be checked by a series combination of five such relay circuits, as shown in Fig. 3. In corresponding fashion, words of ten letters could be checked by a series combination of fifty such relay circuits. A closed path through a long string of such circuits indicates that the incoming word has been found in the dictionary, and this event can be made to initiate printing of the translation stored at the other end of the drum.

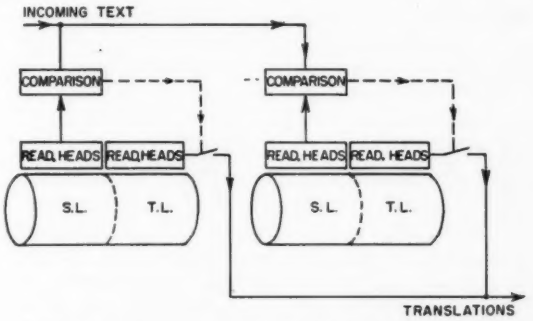


FIG. 4. SCHEMATIC DIAGRAM SHOWING SIMULTANEOUS SEARCH OF TWO DICTIONARY DRUMS

A source-language word with several meanings can be entered in the dictionary several times, each time with a suitable translation. The searching procedure outlined above would uncover each of the possible translations and would make them all available for further consideration. To assist in the subsequent selection of one of these meanings, each translation might have a "tag" stored with it, which would supply grammatical or other necessary information needed by the machine.

With a multiplicity of such circuits, a number of dictionary drums could be searched simultaneously, as suggested schematically in Fig. 4. The incoming text is supplied to all drums at the same time.

(Continued on page 29)

A STUDY OF REACTIONS AT SAND-METAL INTERFACES

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Metal penetration, which results in the entrapment of silicon compounds in the cast surface, is a serious problem in the steel foundry industry. When excessive, this casting defect, known as "burnt-on sand," causes considerable difficulty in machining and finishing steel castings.

According to the commonly accepted theory, the steel at the interface is oxidized and the iron oxide subsequently reacts with silica sand to form fayalite. Investigators have stated that the following factors affect metal penetration and sand adherence: casting temperature, steel composition, metal pressure, grain-size of molding material, permeability of sand mold.

While considerable information is available on the interface reaction products and the mechanism of metal penetration, investigators have not presented any qualitative or quantitative evidence as to physical changes which occurred in the surface layer of steel, nor has any quantitative evidence been presented as to chemical changes which occur in the metal at the casting surface.

Scope of Research Investigation

The present investigation has four main divisions. The first section deals with the preparation of the experimental steel castings for the study of interface reactions. As an aid to understanding the silica sand-steel reactions, other molding materials were also used for castings to be studied in the same manner.

The second section is a preliminary study of the interface reactions. A visual, chemical, and metallographic examination was conducted on the experimental steel castings. In addition, curves were prepared from experimental data showing the relation of hardness to the chemical composition of cast steel.

The third section is a study of the changes in hardness of the steel adjacent to the interface which result from the interface reactions. Since the depth of any physical changes which might occur is very limited, the hardness measurements must be on a micro scale. A correlation was made with the chemical changes which occurred in the metal at the interface.

R. T. Torgerson

The fourth section deals with the determination of structural changes which occur in the steel adjacent to the interface. X-ray diffraction techniques were utilized in the study of the crystal structure of the metal. Precision lattice measurements were made of both the metal adjacent to the interface and the interior of the castings.

Experimental Procedure

The program of experimental investigation was as follows:

1. To pour experimental steel castings under controlled conditions of steel composition, pouring temperature, molding sand, molding techniques, casting shape, and casting size.

2. To determine the effect of molding materials other than silica sand. Castings were poured with silica flour, alumina (Al_2O_3), periclase (MgO), and iron oxide (Fe_2O_3), as molding materials applied as a coating to the mold wall.

3. To determine the relation of hardness to chemical composition. The alloying elements of most importance for this study are carbon, silicon, and manganese. A series of cast steel samples of varying composition were sectioned, and a micro-hardness survey from the surface of the casting to the center was made.

4. To conduct an X-ray diffraction analysis of the metal structure at the casting surface and the interior of the casting for the silica sand and the silica flour mold wash castings.

Preparation of Experimental Steel Castings

One of the primary considerations was to control all the variable factors which might affect the surface

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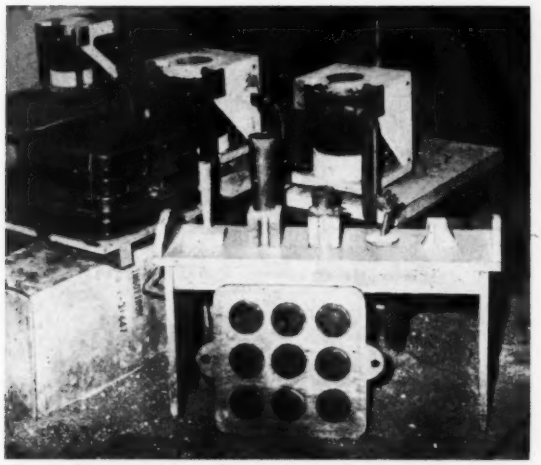

FIG. 1. EXPERIMENTAL CASTING AND PATTERN EQUIPMENT

characteristics: molding sand, molding technique, casting size and shape, steel composition, and pouring temperature.

The molding sand chosen for this work was a green sand mix used by the Technical Research Committee of the Steel Founders' Society.[1] This mix was used for all castings and is given below in parts by weight:

Ottawa #1 silica sand	100
Western bentonite	2.5
Dextrine	1.25
Mogul	0.5
Water	3.0

The sand was mixed in a Simpson mixer and new facing sand was used for each casting. The mold was hand-rammed with approximately the same degree of mold hardness for all molds. Steel flasks, 12-in. by 12-in. with a 4-in. cope and drag, were employed.

The pattern for the castings was a 3-in. cube with a ¾-in. deep V-shaped groove extending vertically down one side. The purpose of the groove, which formed a 60° angle with a ⅛-in. radius at the apex, was to present a mold area susceptible to metal penetration and sand adherence. A 2½-in. diameter tapered combination riser and sprue completed the pattern. The casting weighed approximately 10 lb.

Figure 1 shows this pattern and a completed casting, as well as several other patterns and castings used in steel-casting research.

The melting equipment was a 20-kw Ajax-Northrup high-frequency induction furnace with a capacity of 17 lb of steel. Silica refractory crucibles were used. Figure 2 shows a general view of the melting furnace and pouring equipment.

The composition of the steel varied somewhat in carbon, silicon, and manganese contents. The composition desired was: carbon, 0.35 per cent; silicon, 0.75 per cent; and manganese, 0.50 per cent.

FIG. 2. INDUCTION MELTING UNIT

Since the steel melting stock was deficient in carbon, silicon and manganese, additions of these elements were made to every melt. The impurity elements were the same for all castings. Aluminum and ferro-silicon were used to deoxidize the molten metal before pouring.

The metal temperature was determined with a Leeds and Northrup optical pyrometer, and a pouring temperature of 2850° F ± 20° was maintained for all castings.

Application of Mold Washes

In addition to the standard test castings made with silica sand, a number of experimental castings were poured with other molding materials as mold washes, including silica flour, alumina, periclase, and iron oxide.

A mold wash was prepared from each of these materials by adding 5 per cent western bentonite and 2 per cent raw linseed oil, and mixing with water to a fluidity suitable for spraying. The wash was applied with a pressure-type paint spray gun. The thickness of the mold coating was about 1/32 to 1/16 in.

Preliminary Investigation of Interface Relations

Visual Examination of Experimental Castings. The experimental steel castings were examined for metal penetration, sand adherence, surface roughness and appearance, and characteristics of the sinter layer.

The standard silica sand test castings showed metal penetration and sand adherence. The "burnt on" sand was attached very firmly to the surface and was extremely difficult to remove even by grinding or shot blasting. The V-notch contained the most pronounced sand adherence with very little sinter layer separating from this portion of the casting. The silica flour mold wash casting showed almost no metal penetration or sand adherence. The V-notch

TABLE I

CHEMICAL COMPOSITION OF EXPERIMENTAL STEEL CASTINGS

STEEL CASTING NUMBER	CARBON	SILICON	MANGANESE
1	0.16	0.20	0.51
2	.35	.56	.68
3	.50	.58	.70
6	.33	.64	.76
7	0.33	0.64	0.76

was somewhat rougher than the rest of the casting. The sinter layer scaled off in large pieces with a thickness of about $\frac{1}{16}$ in. The over-all surface condition was good.

The periclase mold wash casting proved to be the most interesting of all the castings. The periclase had apparently not reacted with the metal and there was no sinter layer. The metal penetration and sand adherence were negligible. The excess periclase could be easily removed by brushing or shot blasting.

For better evaluation of periclase as a mold wash, a 4-lb rectangular shaped casting was poured, using periclase wash. This casting also showed a good surface appearance.

The iron oxide wash was used on the 4-lb casting. A reaction occurred between the molten steel and the mold wash which resulted in numerous gas blows and an extremely rough, irregular surface. Iron oxide itself, is apparently not suitable as a mold wash.

Chemical Analysis. A chemical analysis was made of each experimental steel casting for carbon, silicon, and manganese. The chemical composition of the experimental steel castings is given in Table I.

Relation of Hardness to Chemical Composition of Cast Steels. A quantitative determination of the change in hardness that could be expected for a given change in the carbon, silicon, and manganese content in cast steel was necessary for correlating the hardness changes by interface reactions with the possible changes in chemical composition. Three series of cast steel samples were therefore prepared. Since the procedure for preparing the three series was identical, it is outlined for the silicon series only.

A 12-lb heat of steel was melted and 1-lb test casting was poured. A small amount of silicon was added to the remainder of the metal and another test casting was poured. This procedure was repeated until four or five castings were poured. The number of test castings for a series was limited to the number that could be conveniently molded in one flask. These 1-lb test castings will be referred to as *test coupons* in this report.

TABLE II

RELATION OF HARDNESS TO THE SILICON, MANGANESE, AND CARBON CONTENT OF CAST STEEL

TEST COUPON NUMBER	SILICON (%)	MANGANESE (%)	CARBON (%)	HARDNESS (VHN)
1	0.40	0.31	0.16	153
2	1.92	0.31	.16	188
3	3.74	0.31	.16	279
4	4.31	0.31	.16	321
5	0.42	0.78	.23	195
6	0.42	1.15	.23	225
7	0.42	1.87	.23	263
8	0.42	2.90	.23	308
9	0.42	0.35	.17	160
10	0.42	0.35	.22	183
11	0.42	0.35	.26	198
12	0.42	0.35	0.34	226

Each test coupon was analyzed for carbon, silicon, and manganese and the hardness was determined with the Kentron micro-hardness tester, with results given in Vickers diamond pyramidal hardness numbers (VHN). (See Table II.) The quantitative relation of hardness to chemical composition determined experimentally for cast steel is illustrated in graphical form in Fig. 3.

Metallographic Examination. The standard test casting was cut into sections and metallographic specimens were prepared and examined. The samples were etched in picral.

The metallographic examination showed clearly that chemical changes occurred in the steel adjacent to the interface. An etch-resistant zone was found to extend for about 0.040 in. into the casting. Examination revealed that this zone is composed almost entirely of ferrite, while the interior of the casting is composed of about 75 per cent pearlite and 25 per cent ferrite. A photomicrograph of a sectioned casting may be seen in Fig. 4, showing the etch-resistant zone at the surface, with decreasing amounts of ferrite progressing towards the center of the casting.

Examinations of specimens prepared from the other experimental castings revealed substantially the same microstructure as that of the first casting. Relative amounts of ferrite and pearlite and the thickness of the etch-resistant zone varied for the castings, depending upon the carbon content of the steel.

Changes in Hardness of Steel from Interface Reactions

Micro-Hardness Testing. In this study to determine changes in hardness of steel by interface reactions, a Kentron micro-hardness tester with a Vickers 136° diamond pyramid indentor was used to run a hardness survey from the surface to the

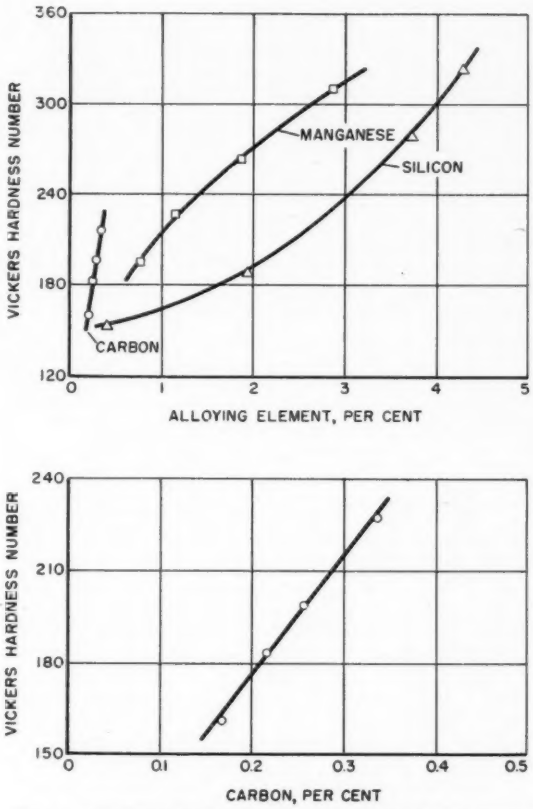

FIG. 3. RELATION OF HARDNESS TO SILICON, MANGANESE, AND CARBON CONTENT OF CAST STEEL

center of the experimental steel castings. The hardness values are calculated in Vickers pyramid hardness numbers (VHN).

The first indentation of the hardness survey was 0.04 in. from the surface, with an indentation every 0.004 in. through the etch-resistant zone. Greater intervals between indentations were allowed progressing toward the center of the casting. The indentations were approximately 0.002 to 0.003 in. sq.

Results of the Micro-Hardness Tests. The results of the micro-hardness tests were plotted in the form of a curve of hardness as a function of the distance from the cast surface. A typical hardness curve for one of the experimental steel castings is shown in Fig. 5. The curve clearly shows that the steel adjacent to the surface is considerably lower in hardness than the interior of the casting. There is a rapid increase in hardness progressing inward from the surface for a distance of from 0.030 to 0.050 in., after which the hardness remains constant.

A comparison of the results of this test reveal that the higher the carbon content in the steel, the more pronounced is the decrease in hardness of the metal

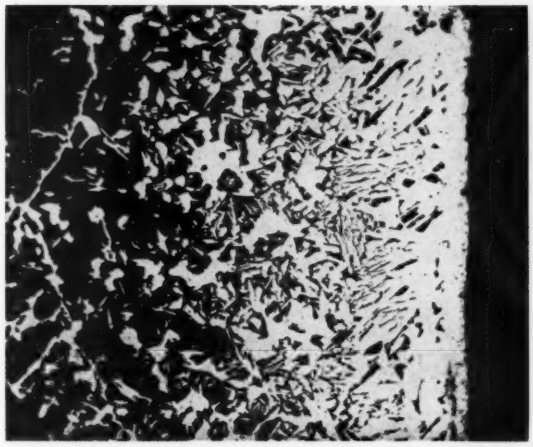

FIG. 4. PHOTOMICROGRAPH (× 50) OF AS-CAST STRUCTURE OF CAST STEEL

adjacent to the surface. Casting No. 1 shows only a slight decrease in hardness near the surface for the standard silica sand casting which contained 0.16 per cent carbon. Casting No. 2 shows a greater decrease in hardness near the surface for the silica flour mold wash casting which contained 0.35 per cent of carbon. Casting No. 3 shows a much greater decrease in hardness near the surface for the alumina mold wash casting which contained 0.50 per cent of carbon.

The direct correlation of the carbon content to the magnitude of the decrease in hardness near the surface is in agreement with the results of the metallographic examination. The mechanism of the reactions at the interface cause a decarburization of a layer of steel at the surface. The removal of the carbon reduced the amount of the pearlite constituent and increased the amount of ferrite which is considerably softer than pearlite, resulting in a decrease in hardness of a metal zone adjacent to the interface.

No reaction was noted between molten steel and the alumina or periclase wash nor could any difference in hardness of the surface layer be attributed to these mold washes. It can be concluded that the hardness characteristics for an alumina or periclase mold wash casting are identical to those of silica-sand mold or silica-flour mold wash castings of the same carbon content.

The hardness curve for the iron oxide mold wash casting shows a greater decrease in hardness near the surface than for other castings with the same carbon content. This results from the reaction of molten steel with the iron oxide which provides additional oxygen for the more rapid decarburization of the surface layer of steel.

The micro-hardness tests have confirmed that one of the primary interface reactions is the depletion of

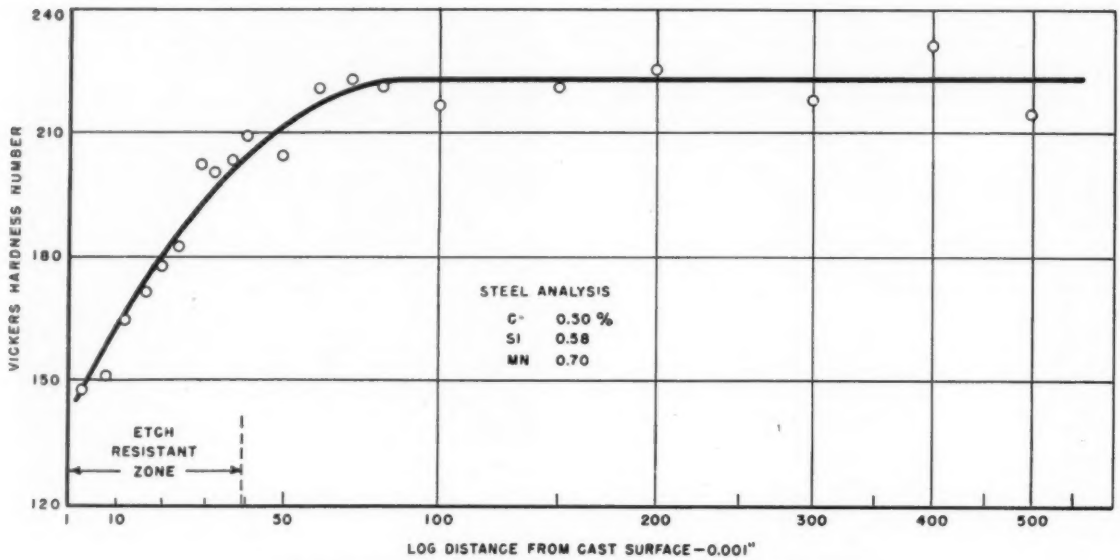

FIG. 5. HARDNESS AS A FUNCTION OF DISTANCE FROM CAST SURFACE (Casting No. 3)

carbon in the steel at the interface by oxidation. Less conclusive is the information on the changes in silicon and manganese content near the interface. The hardness curves have established that there is definitely no increase in either silicon or manganese at the surface, and if there is a decrease in these elements by oxidation it is extremely small as compared to the depletion of carbon.

No apparent change in hardness is attributable to a depletion of silicon or manganese at a distance of 0.004 in. from the surface. If there is a depletion of these elements, it is either too small in magnitude to be detected by this method, or the depletion does not extend more than 0.004 in. from the surface.

X-Ray Diffraction Study of Sand-Steel Interface Reactions

Known Facts and Theoretical Considerations. The micro-structure of as-cast steel castings is an aggregate of ferrite (body-centered-cubic alpha iron) and pearlite (eutectoid). When 0.35 per cent C steel solidifies, the first crystallization which occurs is the formation of austenite. Upon further cooling a secondary recrystallization of the solid austenite takes place as the cast steel cools through its critical range. The austenite transforms into a network structure of ferrite and pearlite. This is the structure of cast steel observed in the as-cast condition at atmospheric temperature conditions.[2]

Pearlite is composed of alternate plates of ferrite and cementite; therefore, the structure of cast steel is essentially ferrite with a small amount of iron carbide. A change in the amount of carbon will change the amount of cementite, and hence pearlite, but will have no effect on the crystal structure of ferrite.

The alloying elements, silicon, manganese, chromium, nickel, and copper, will form substitutional solid solutions with iron and are present in the ferrite structure of cast steel. Atoms of these elements replace iron atoms in the body-centered-cubic crystal lattice of ferrite. Since the force fields and diameters of these atoms differ from those of the iron atoms, they will not fit perfectly in their allotted space in the lattice and will distort the crystal lattice in their neighborhood.[3]

This lattice distortion has a pronounced effect on the properties of the metal. The slip planes are roughened or distorted so that slip is made more difficult and the metal becomes harder and stronger.

Alloying elements are not the only cause for lattice distortion. According to Taylor,[4] the major causes of lattice distortion (stresses and strains) in a metallic crystal lattice are the following: alloying elements, cold working (plastic deformation), thermal shock or treatment, elastic deformation.

The ferrite structure, composed of pure iron, has a lattice constant (a_0) of 2.8607 Å. The atomic diameters of iron and other elements of importance in this investigation are as follows:[5] αFe—2.48 Å; γFe—2.52 Å; Si—2.34 Å; Mn—2.58 Å.

From the atomic diameters, it can be surmised that an addition of silicon to steel will cause the smaller silicon atom to distort the crystal lattice. The net effect will be to decrease the lattice constant of

TABLE III

RELATION OF LATTICE CONSTANT TO THE SILICON CONTENT OF ALPHA IRON[6]

PHASE	SILICON (%)	LATTICE PARAMETER (Å)		CRYSTAL STRUCTURE
Alpha	0.0	2.8604		B.C.C.
"	2.38	2.8580		"
"	5.16	2.8535		"
"	10.76	2.8327		"
"	15.70	2.8164		"
"	18.25	2.8092		"
Fe_3Si_2	25.00	6.727	4.705	Hexagonal

the ferrite. On the other hand, manganese, which has a larger atomic diameter than iron, will also distort the lattice. In this case there will be an increase in the lattice constant of ferrite due to the larger size of the manganese atom.

Jeffe and Greiner[6] made a study of the solid solution of silicon in alpha iron. Their determination of lattice constants for various silicon contents in alpha iron is given in Table III.

The determination of structural changes which occur in the steel adjacent to the interface should be of great value in establishing the nature of the reactions which occur at the sand-metal interface. X-ray diffraction techniques were utilized to study the structure of metallic crystal lattices. The same test coupons prepared for the hardness vs. composition tests were used for this purpose.

X-Ray Diffraction Unit

A North American Philips X-ray diffraction unit was used for the X-ray diffraction studies. The unit consists of a Philips high-angle X-ray diffractometer goniometer and a Brown potentiometer recorder. The goniometer rotates the sample and the Geiger-Mueller counter tube so as to scan all angles of 2θ from $\theta°$ to 160°. The Brown potentiometer chart recorder makes a continuous record of the position and intensity of the reflected X-ray beams which are picked up by the counter tube.

The rate of scanning by the goniometer governs the sensitivity of the recording of the reflected X-ray beams, and is controlled by changing gears to obtain scanning speeds of from ⅛° to 2° (2θ per minute). The Brown recorder chart speed may also be controlled by changing gears to obtain speeds of ⅛ in. to 2 in. per minute.

An iron target X-ray tube was used in the diffraction studies. By using a manganese filter, a monochromic beam of X-rays ($Fe_{K\alpha_1}$) was obtained. It was found necessary to employ iron radiation since an X-ray beam of shorter wave length would cause the generation of secondary X-rays in the steel sample, and the recording of these secondary X-rays by the Geiger-Mueller tube would obscure the primary diffracted beam, reducing considerably the accuracy of measurements of the Bragg angles.

Preparation of Samples. The preparation of metal samples for precision lattice determination requires care. A good sample must have a smooth, flat surface free from lattice distortion induced by mechanical deformation. Samples which have been sawed, ground, or mechanically polished require the removal of the deformed surface layer by etching or electrolytic polishing and etching.

The samples from the surface of the steel castings were removed from the smoothest area of the casting with a power saw and were cut so as to obtain a surface area of 1 by 1½ in. and a thickness of ⅜ in. Silica and silicate compounds were removed from the cast surface by etching for 30 minutes in concentrated hydrofluoric acid containing 1 per cent thiourea in order to inhibit the dissolution of metal. After being washed and dried, the sample was ready to place in the X-ray diffractometer.

The sample representing the interior of the casting was prepared by sawing a section 1 by 1½ by ⅜ in. thick from the casting. One surface was ground flat with a felt grinder and polishing papers through 00 emery paper. Mechanical deformation was removed by electrolytic polishing and etching with a perchloric acid etch.

Procedure for Measuring Lattice Constants. The first consideration was to establish the position of the Bragg reflections from the ferrite crystal lattice using $Fe_{K\alpha_1}$ radiation. A sample from the casting was placed in the diffractometer sample holder and scanned between the 2θ angles of 0° to 160°. The scanning speed was 2° (2θ) per minute. It should be noted that all the equipment is designed to give angles of twice the Bragg angles, and all charts and tables give values of 2θ rather than θ.

The diffraction pattern obtained for Casting No. 2 is shown in Fig. 6. The four diffraction lines represent diffractions from the lattice planes (110), (200), (211), and (220)) of ferrite. Table IV lists these planes, the Bragg angles, and the interplanar spacings for Steel Casting No. 2. In addition, the theoretical values are listed for a ferrite crystal structure composed of pure iron.

The location of the ferrite diffraction lines indicated that (220) reflection plane at 145.60° (2θ) had the most satisfactory requirements for precision lattice measurements. Check measurements were also made for the (211) plane at 111.6° (2θ).

The precision lattice measurements were made by scanning the sample at a slow speed (½° 2θ per minute) from 144° to 147° for the (220) plane and

(Continued on page 30)

Suspension-Bridge Report Completed

PARTS IV AND V OF BULLETIN No. 116, *The Aerodynamic Stability of Suspension Bridges* (with special reference to the Tacoma Narrows Bridge), have been issued, completing this publication, the first part of which appeared five years ago. The investigations began in February, 1939.

The early phases of these studies were initiated at the request of the Washington State Department of Highways, although, after the failure of the bridge in 1940, the U. S. Bureau of Public Roads joined with the Washington Toll Bridge Authority in sponsoring continued research.

Since July 1, 1947, the project has been conducted under the joint sponsorship of the Bureau of Public Roads and the University of Washington. F. B. Farquharson, Professor of Civil Engineering and Director of the Engineering Experiment Station, has directed the project since its inception. George S. Vincent, Principal Bridge Engineer of the Bureau of Public Roads, has been associated with the project since 1942, and Frederick C. Smith, Professor of Civil Engineering, devoted a considerable portion of his time for the five years following the summer of 1940 to this investigation.

Part I, "Investigations Prior to October, 1941," by Professor Farquharson, presents the background for the study, and describes construction of the original Tacoma Narrows Bridge, its behavior, and final failure, covering all investigations up to the time a contract was arranged for building a special wind tunnel to study wind-actuated models.

During the four months intervening between the opening of the original bridge to traffic and its failure on November 7, 1940, it was under constant observation, and the various modes of motion it developed were recorded extensively and were duplicated as far as practicable on the dynamic model which had replaced the original static model in the wind tunnel.

The development of aerodynamic theories during these early studies is discussed in Part I, and the results of the static wind-tunnel tests on the section model with modifications are presented.

Part II, "Mathematical Analyses," by Frederick C. Smith and George S. Vincent, develops formulas based on the various modes of motion displayed by the original bridge and its model, and tests on the model with several structural changes.

Part III, by F. B. Farquharson, is devoted to investigation of the full and section models of the original bridge under the action of wind. A chapter reporting on parallel tests carried on at the California Institute of Technology by Drs. Theodore von Kármán and Louis G. Dunn, is included.

Part IV, also by Professor Farquharson, presents the entire picture of the construction and erection of the full and section models and the aerodynamic tests on various configurations which influenced the final design of the new bridge.

Part V, by Mr. Vincent, extends the theoretical studies into a suggested pattern for predicting the behavior of suspension bridges from the experimental data based on the new Tacoma Bridge and its models, supplemented by evidence from models of the Golden Gate, George Washington, and Bronx-Whitestone bridges, and the proposed design for the Paseo Bridge at Kansas City. Field measurements were also taken on two small bridges in Washington.

A limited number of copies of all parts of this bulletin are available on request, without charge. Address: Publications, Engineering Experiment Station, University of Washington, Seattle 5.

MICHIGAN BRIDGE MODEL TO BE TESTED

A 50-scale model of the proposed Mackinac Straits Bridge is being constructed in the Structural Research Laboratory of the Civil Engineering Department, and will be tested this summer in the bridge wind tunnel, under the supervision of Professor F. B. Farquharson, Director of the Experiment Station. Professor Farquharson has just returned from the East where he conferred with the consulting engineer for the bridge.

The wind tunnel, erected at the time of the failure of the Tacoma Narrows Bridge, provides the only facilities in the world for this type of testing. Models of both the original and new Tacoma bridges were tested, and in 1952, following the dangerous oscillations of the Golden Gate Bridge, tests were made on a 75-scale model of that bridge.

The Mackinac Straits Suspension Bridge, which will connect Lake Superior and Lake Michigan, will have a main span of 3,800 feet, exceeded only by that of the Golden Gate Bridge (4,200).

Repeated tests with both full and section models of the Tacoma Narrows Bridge led to the conclusion that tests with a section model are adequate to provide all necessary aerodynamic data at about 2 per cent of the cost of a full model.

Engineering Teachers "Retire" to Active Professional Life

R. G. Tyler F. M. Warner F. C. Smith Joseph Daniels

FOUR PROFESSORS OF ENGINEERING whose teaching careers at the University of Washington cover a total period of 131 years, retired from the academic scene last June.

Joseph Daniels, senior in point of affiliation with the University, came here in 1911 from the faculty of Lehigh University where he had earned a master's degree in 1908, following graduation from the Massachusetts Institute of Technology in 1905. From 1911 to 1954 he taught undergraduate and graduate courses in mining and metallurgy. He has been especially interested in the coal resources of Washington and his report on that subject, published in 1934 by the Engineering Experiment Station, is still in demand. Numerous articles have appeared under his name in technical journals and he is also co-author of a number of publications of the Northwest Experiment Station (U. S. Bureau of Mines). Professor Daniels has been a mining consultant and will continue in that capacity in private life.

Next of the four to join the faculty was Frank M. Warner who began to teach engineering drawing at the University in 1913. He had obtained the degree of B.S. in M.E. at the University of Wisconsin, followed by teaching at his alma mater, and two years at Washington State College, Pullman, and a few years of private practice in Spokane. In 1918 he gave up teaching and joined the Alberni Pacific Lumber Company in British Columbia, where he remained as assistant manager until 1925. The teaching profession, however, continued to attract him, with the result that in 1925 he returned to the University. In 1937 he was promoted to the rank of a full professor of General Engineering. Professor Warner's text book, *Applied Descriptive Geometry,* is in its fourth edition, and its sales recently passed the 135,000 mark.

Frederick C. Smith, the only one who is an alumnus of the University, began as an instructor in general engineering in 1925, the year before he received his B.S. degree. In 1929 he earned his professional degree in civil engineering and was transferred to that department, where his courses have dealt primarily with mechanics, and strength and properties of materials. With George S. Vincent, he is co-author of Part II, "Mathematical Analyses," of Bulletin 116, *Aerodynamic Stability of Suspension Bridges,* and has published other technical articles. He, also, will continue his work as consultant.

Richard G. Tyler obtained a C.E. degree from the University of Texas in 1908 and a B.S. in C.E. from the Massachusetts Institute of Technology in 1910. After engaging in professional practice in sanitary engineering, including experience as a city engineer in Texas, he began teaching at the University of Texas in 1916. He also taught at Oklahoma A. & M. and at M.I.T. before coming to the University in 1929. From 1929 to 1936 he was Dean of the College of Engineering and Head of the Department of Civil Engineering. Since 1935 he has served as Professor of Sanitary Engineering. Professor Tyler has a long record of consulting practice in his special field and has done extensive research. His list of publications is impressive and includes the "Report of an Air-Pollution Study for the City of Seattle." He served as Chairman of the King County Planning Commission from 1934 to 1941.

NEW TEXT ON ELECTRIC FIELDS BY ROGERS

INTRODUCTION TO ELECTRIC FIELDS. Walter E. Rogers. New York. McGraw-Hill Book Company, Inc., 1954. 333 pp. $7.50.

This book, according to the author's preface, has the purpose of presenting "Maxwell's equations to the student as a logical summary of some real analytical experience in the use of vector methods." It is designed as a text for a one-quarter undergraduate course in Electrical Engineering at the University of Washington.

The first of the eleven chapters is an introductory one on Vector Analysis. There follows a sequence of seven chapters on Electrostatics through which the author develops successively more refined methods for handling problems in this subject. The sequence begins with direct applications of Coulomb's Law, proceeds to a discussion of potential, stresses for future reference the methods based on analysis of current flow in conductors, and touches on the uses of Gauss' Law and the method of images. One chapter in the sequence deals with dielectrics, and its culmination is a somewhat detailed study of the theory and application of the equations of Laplace and Poisson. In a chapter on the Magnetostatic Field, the experimentally observed force on a moving charge serves as the basis for definition of the magnetic field vector. The author attains his goal, a formulation of Maxwell's equations, in the next chapter. The book ends with a description of vector potential methods for magnetostatic problems. Each chapter lists references and provides problems for exercise. Each of the first nine chapters ends with a paragraph of summary and critical comment on the concepts and methods of the subject chapter. The book is illustrated with four types of figures. Line drawings are clearly done and sketches, in perspective, of Gaussian surfaces and some fields are most helpful in presenting many of the abstract ideas. There are photographs of rubber-sheet models, illuminated with light projected through a grating, that make impressive illustrations of potential distributions. Another fine set of photographs, prepared by A. D. Moore of the University of Michigan, utilizes the similarity between electrostatic and fluid-flow problems to visualize field lines. Crystals of potassium permanganate, placed strategically in a thin sheet of flowing water, disolve and trace out flow lines just like those theory predicts. Professor Moore has developed techniques for simulating sources, sinks, conducting surfaces and most of the scenery of the electrostatic field.

The author makes a deliberate attempt to hearten students by employing an informal style and providing frequent statements of the motivation for procedures that might otherwise seem abstruse. New concepts, physical and mathematical, develop slowly from elementary and familiar ideas, particularly in the early chapters. As might be expected in an engineering text, even one on electric fields, the subject matter is largely drawn from practical problems. Analogy, wherever possible, with current flow in conductors is another point for students with previous training in electricity.

It seems strange at the present time to find not even a brief mention of wave propagation. The severe limitation on subject matter imposed by the quarter system makes it likely that even the material already presented will be covered with difficulty. However, the careful building of confidence in vector methods and the final statement of Maxwell's equations could, in this reviewer's opinion, be exploited profitably by a short chapter designed to stimulate students to look further into this important subject.

There are, as in all first editions, a few points requiring correction. For instance on pages 11 and 101 are equations dimensionally inconsistent. At the beginning of paragraph 2.2 is an obvious misstatement of Coulomb's Law. In equation 5 of page 103, ζ is *not* the magnitude of a vector quantity, while equation 4 of page 188 employs an unconventional differential relation. Certain other criticisms are more nearly, perhaps, matters of individual taste. One might wish for a stronger statement of the boundary conditions on the field vectors at an earlier point in their development instead of requiring (temporarily) their assumption as on page 182. The beginning of paragraph 2.2 might better state that observation of forces of attraction and repulsion requires the assumption of two types of charge instead of implying the reverse. Equation 1 on page 212 is more clearly justified on the basis of energy conservation than equality of kinetic and potential energy.

In spite of minor points such as those above, the author's objective is met to an admirable degree. The book proceeds in a deliberate and well-organized fashion to develop experience with and a feeling for vector methods. Students should emerge from a study of this text with thorough grounding in electro- and magnetostatics, confident in their ability to tackle advanced applications in many fields.

RONALD GEBALLE
Department of Physics
May 3, 1954

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Dircetor of the Engineering Experiment Station, University of Washington, Seattle 5.

HOGAN, D. F., "Design and Use of Ejector and Draft Tube for the Ozonation of Water." M.S. in Civil Engineering, 1954.

This thesis continues the study reported by D. E. Scholen.* It is limited to tests on water for drinking purposes, and deals prmarily with the design of an efficient diffuser tube to be used with Scholen's ejector, for getting better and more dependable sterilization with ozone.

The Scholen ejector had a $\frac{5}{16}$-in. nozzle and an expander with diameter from $\frac{31}{64}$ to $\frac{51}{64}$ in., length, 2.56 in., and a 7° taper. The ozone diffuser tube, the design of which was one objective of this research, consisted of three 2-ft sections of 1¼-in. diameter plastic tubing connected end to end, separated by diffuser diaphragms with centrally located orifices of the correct size to keep the diffuser tube hydraulically balanced and also to break up the air bubbles at each orifice. The air and ozone discharge from the ejector, appears as a fog of very small bubbles which, as the mixture passes down the tube, agglomerate to form air pockets or large bubbles. This greatly reduces the surface of water-ozone contact, and it is necessary to break the air up again into fine bubbles. This is done by properly designed and located orifices in the tube.

Many tests were made and results observed, using different types and arrangements of diffuser diaphragms. These diaphragms were made from plastic blanks turned to the diameter of the tube. The head loss through the orifice was appreciable. Attention should be given to a redesign of these diaphragms for producing less head loss. The final design used nine $\frac{7}{32}$-in. holes in the first diaphragm and nineteen $\frac{9}{64}$-in. holes in the second, giving total areas of 0.339 and 0.297 sq in. respectively, which were 27.9 and 24.1 per cent of the tube area. Good diffusion was obtained throughout the full length of the tube under adequate pressures.

The discharge end of the diffuser tube was fitted with a ½-in. tube and a $\frac{9}{16}$-in. rubber hose to the sink. The residual ozone was negligible when efficiently operated. A valve in the discharge line regulated the back pressure in the diffuser tube as desired. The diffuser tube operated best in a vertical position discharging downward. The horizontal position encouraged the coalescence of the air bubbles, greatly reducing the efficiencies.

Many tests were made to determine the hydraulic characteristics of the ejector and diffuser tube for each of the two ozonators used. The tube was calibrated for each. The maximum quantity of ozone that could be applied with these ozonators was 1 ppm. Ozone residuals were checked at all pressure points (at the ejector, above and below each diffuser diaphragm, and before discharge). All points, except the one before the discharge, showed a residual greater than the 1 ppm dose being used. Good bacteriological kills were obtained up to a specific flash chlorine demand. Comparative bacteriological tests were made on water immediately after treatment and also after the sample had been allowed to stand in a closed sample bottle for 15 minutes. It was found that 0.1 ppm less ozone was required to obtain a bacteriological kill with 15 minutes detention.

Tests were conducted, therefore, to determine the advantages of a final detention tank. Results of these tests with the detention tank were the same as those obtained when the ozonated water samples were held in closed sample bottles. No advantage was gained by allowing the ozonated air to bubble up through the treated water as is done in European practice. Immediate or flash chlorine demand determinations were made of the untreated water for all tests. A series of flash chlorine demand determinations were made on the treated water. It was found that a bacteriological kill could be obtained without appreciably reducing the flash chlorine demand of the treated water. No relationship was established between the amount of ozone applied and the reduction in the flash chlorine demand. Samples taken from different points in the diffuser tube indicated that the kill was progressive throughout the length of the tube.

(Continued on page 32)

* D. E. Scholen, "Hydraulic Jet Air Ejector for Ozonating Drinking Water," M.S. thesis Uni. of Wash., 1952. Abstract, *The Trend in Engineering*, April, 1953, p. 30.

ABOUT SUSPENSION BRIDGES

(Continued from page 1)

Venice in 1595 (1617?) but was never built, had rods composed of eyebars supported by vertical suspenders,[4] yet the Dryburgh Abbey Bridge (Scotland) when rebuilt (1818) is reputedly "the first to use eyebars."[3] The earliest date for an iron chain suspension bridge on the continent is 1734, in Prussia. The first in England, in 1741, the Winch Bridge, of chains with no stiffening, had a span of 70 feet, and was only two feet wide. When it fell in 1802, it was replaced by one of a similar type which was still standing in 1908.[3]

In 1801 the first suspension bridge in America was built across Jacob's Creek, Pennsylvania, by James Finley. It cost $6,000 and was warranted for 50 years "all except flooring." Finley's design, patented in 1808, was destined to be used for some eight other bridges built by the designer and to affect more than a score of other contemporary structures.

"The principal features of his invention consisted in the application of artificial stone abutments, in the introduction only of two chains, one at each side of the bridge, the links of which were as long as the distances between the cross-bearers or joists. Finley applied one-seventh of span for the deflections of cables, introduced suspension rods and stirrups to support the joists and arranged the anchor chains at the same angles as the main chains, to avert powers acting to thrown down the piers.

"The most interesting of the novelties, and one upon which Finley apparently laid a great value, was the arrangement for distributing the load over a great extent of the bridge, thereby aiding to divide it over many suspenders, and to stiffen the otherwise movable floor against change of shape."[5]

Finley's bridges were widely publicized by J. Cordier's *Histoire de la Navigation Interieure* (1820) in France, and may have led to the spate of suspension-bridge building in that country, beginning with the small Annonay Bridge (one span of 59 feet) built by the Seguins in 1823, followed in 1825 by the first "large" suspension bridge in France, the Pont de Tournon, by the same builders. This bridge of two spans, each more than 278 feet long, and 13 feet 9 inches wide, had a stiffened parapet and 12 main cables, each of 112 wires.[3] From 1823 to 1842 some 115 suspension bridges were built in France.

The Geneva Bridge of 1823 in Switzerland, built by Col. Dufour was the first "large" iron wire bridge. It had two spans of 131 feet each and was 6 feet wide. Six parallel cables contained 90 wires, each.[3] (Compare with a Golden Gate cable, 36⅜ inches in diameter, containing 27,572 wires.)

Brooklyn Bridge, designed and built by the Roeblings, father and son, and completed in 1883, marked a highlight in suspension-bridge design and was the subject of hundreds of articles, reports and discussions during the 13 years of its actual construction.

The elder Roebling (John A.) had previously built the Cincinnati Bridge (1867) which was the longest suspension bridge prior to Brooklyn Bridge, with an over-all length of 1,619 feet and a main span of 1,057 feet, the Niagara Bridge (1855), which was a double-deck highway and railway bridge, and five suspended aqueduct bridges.

The main span of Brooklyn Bridge is nearly 1,600 feet long, with two side spans of 930 feet each and a width of 85 feet. It has six trusses and four cables, each 15¾ in. in diameter and containing 5,296 wires. In Roebling's designs the adequate weight and stiffening provisions for traffic loads and conventional static wind pressure resulted in the stability for which his structures have been noteworthy. Unfortunately, during the following years, the longer spans, together with the lighter stiffening structures (deemed adequate with the trend toward highway traffic, only), resulted in reversion toward the ancient weaknesses which centuries of trial-and-error had just overcome. And here, in review, the picture reveals a factor which designers had failed to take into account: the possible development of aerodynamic forces which, under certain conditions, might cause catastrophic oscillations.

A survey of failures of suspension bridges shows that in Great Britain, between 1818 and 1839, the failure of five bridges was due to wind. In order of the date of major failure, they are as follows:[6]

Dryburgh Abbey	1818
Union	1821
Brighton	1836
Montrose	1838
Menai Straits	1839

In the United States the following three bridges suffered similar failure during the period 1854-1889:[6]

Wheeling	1854
Niagara-Lewiston	1864
Niagara-Clifton	1889

Between 1937 and 1940 five suspension bridges which were opened to traffic experienced more or less difficulty with wind: Golden Gate, Thousand Islands, Deer Isle, Bronx-Whitestone, and Tacoma Narrows Bridge. Four of these (all but the Golden Gate Bridge) were stiffened with solid-plate girders, and had shown signs of undue instability during the latter phase of their construction period, and on all four some emergency remedial measures were taken. Since these bridges were not only unorthodox in the shape of their stiffening construction, but

were only slightly stiffened apart from the action of the cable, there was always some confusion regarding oscillations which were traffic-generated and those which had their origin in the wind. Installation of the center diagonal stays on the Thousand Islands, the Deer Isle Bridge, and the Bronx-Whitestone Bridge, was largely for the purpose of preventing an undulating type of vertical motion (a single-moded motion) which appeared to arise from the traffic. Such stays were also installed in the Tacoma Bridge at a later date, but on this structure it was evident that such motion could arise either from traffic or from wind. Although the Golden Gate Bridge showed many indications of motion almost from the date of its opening, the oscillations were generally of a very mixed character and rarely reached double amplitudes in excess of 40 inches (measured at the edge of the sidewalk at approximately the quarter point of the main span). However, in a storm which developed on December 1, 1951, a condition arose in which for a short period of time the bridge moved in the first asymmetric torsional mode, with double amplitudes at the quarter point in excess of 12 feet. As a result of the damage done on this occasion and the fear of the recurrence of this motion, a decision was made to increase the structural stiffness of the suspension structure through the addition of a bottom lateral system. This work is now in progress (summer, 1954).

Of the five plate-girder-stiffened bridges built during this period, the Tacoma Narrows Bridge, being located in a completely exposed situation and having the world's third longest span, developed unprecedented motions in the vertical modes. Finally in November, 1940, it succumbed to a catastrophic torsional motion which arose either from a failure of the center diagonal stays or, more probably, from an initial failure of the lateral system at mid-span. In the meantime, the Bronx-Whitestone Bridge had developed vertical motions which were objectionable to traffic, and plans were prepared for increasing the stiffness of this structure by the addition of a truss structure above the original plate girder, making the plate girder essentially a bottom chord of the truss. This modification was not accomplished until after the end of the war.

Little information has been made available regarding the behavior of the Deer Isle Bridge in storms which occurred during the winter of 1942-43, but it is clear that, in spite of numerous remedial measures in the form of stays applied to this structure, this bridge moved during these storms in a catastrophic vertical mode (fundamental mode with one wave), where a double amplitude is reported to have approached 25 feet. Many of the stays were broken and the structure suffered considerable damage. It is probable that its great flexibility both in towers and suspended structure was responsible for the fact that it withstood the onslaught. Subsequently the bridge was repaired and stabilized by many additional stays, including diagonal crossroad stays. This is the only suspension bridge upon which a catastrophic type of vertical mode has been observed.[7]

A rather large number of tests conducted on oscillating section models of some existing bridges and with numerous variations in configuration, suggest the probability that most, if, indeed, not all, existing suspension bridges are basically aerodynamically unstable. The fact that very few suspension bridges have shown evidence of any significant motion under the action of wind may be due to either or both of the following possibilities:

1. The combined stiffness arising from the suspended structure and the cable system may result in a natural frequency in the various modes at so high a vibration value that the critical wind velocities to excite the modes are never reached. Such a situation undoubtedly arises in all double-decked structures.

2. Since the wind excitation of a suspension bridge is dependent on the steadiness of the wind and its angle of attack, both vertical and horizontal, and the optimum wind direction may be rather narrowly confined, many basically unstable bridges have probably never been exposed to their optimum wind.

Terrain is the controlling factor in such cases, of which the Golden Gate Bridge provides the best example. Here is a structure which performed creditably for 14 years before the correct wind conditions arose to take advantage of its unstable characteristics (which had always been present) and to generate the extremely disturbing oscillation which had been predicted in the laboratory.

Nothing short of a meticulous aerodynamic investigation of all existing major suspension bridges can reveal the true margin of safety inherent in their ability to resist wind action.

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Notes and Comments

ENGINEERS IN THE NEWS

J. I. MUELLER, Associate Professor of Ceramic Engineering, attended the meeting of the American Ceramic Society in Chicago, April 19-23, where he read a paper on "Construction of a Building Utilizing Prefabricated Prestressed Ceramic Tile Structure Units" before the Division of Structural Clay Products.

E. E. MUELLER, Assistant Professor of Ceramic Engineering, also was on the program of the American Ceramic Society, presenting a paper on "A Laboratory Continuous Tunnel Kiln" before the Division of Materials and Equipment.

W. A. SNYDER, Assistant Professor of Mechanical Engineering, who attended the meeting of the American Foundrymen's Society in Cleveland, May 12, appeared on the program with a paper on "Olivine-Silica Molding Sands." Co-author of this paper was **G. S. SCHALLER,** Professor of Mechanical Engineering.

R. G. HENNES, Professor of Civil Engineering, was honored with the certificate of recognition awarded annually by the student chapter of Washington State College for "outstanding performance in the interests of Northwest highways." Professor Hennes teaches highway courses at the University of Washington and is chairman of the Washington State Council for Highway Research.

NEW REPRINTS

Reprint No. 76. "Applying the Engineering Method to Report Writing." J. W. Souther, *Mach. Des.*, Dec., 1952.

Reprint No. 77. "Bandwidth Nomograph for Pulse Filter Network." B. L. Adams, T. M. Stout, *Electronics,* Dec., 1952.

Reprint No. 78. "A Block-Diagram Approach to Network Analysis." T. M. Stout, *AIEE Trans.*, 1952.

Reprint No. 79. "Block-Diagram Solutions for Vacuum-Tube Circuits." T. M. Stout, *AIEE Trans.*, Nov., 1953.

Reprint No. 80. "Determination of Hydrogen Sulphide, Methyl Mercaptan, Dimethyl Sulphide and Disulphide in Kraft Pulp Mill Process Streams." V. F. Felicetta, Q. P. Peniston, J. L. McCarthy, *TAPPI,* Vol. 36, No. 9 (Sept., 1953).

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E. R. LAB TRANSFERRED TO SCHOOL OF MEDICINE

Since the Environmental Research Laboratory was organized in March, 1951, it has been under the supervision of an administrative committee whose members were drawn from various fields of interest. The purpose of this committee was to coordinate the many technical activities of the laboratory. However, as time progressed, the committee's main chores were to solve internal problems of financing, to determine whether any academic work was to be done, etc. It became increasingly apparent that the ERL needed a "home."

Because the activities of the ERL are so closely linked with public health and industrial medicine, the logical "home" was in the Department of Public Health and Preventive Medicine, School of Medicine. Consequently Dr. Haviland, Acting Dean of the School of Medicine, offered to "adopt" the ERL, and the University administration approved the transfer for July 1, 1954.

In no way will this transfer affect the present policies of the ERL with respect to its industrial health and air-pollution activities. However, in addition to the ERL's present work it is hoped that staff members will be able to contribute to the teaching program and undertake some work along the lines of pure research. The advisory committee, which will be continued, will revert to its original purposes of providing recommendations on technical matters.

Recent investigations of the Laboratory have concerned the toxicity of methanol used in duplicating machines, the cause of the excessive windshield pitting reported in some Washington communities, and air concentration of lead fumes and dust in a body-finishing shop.

COMPUTING MACHINES FOR LANGUAGE TRANSLATION

(Continued from page 15)

Correspondence between the incoming word and a dictionary entry is noted on only one drum, from which the translation is obtained. Parallel operation of this type would permit a dictionary of any desired size with the access time of a single drum, but at a considerable price in additional checking circuits.

In a practical comparison system crystal diodes, transistors, or vacuum tubes would be used instead of relays. These elements have no moving parts to limit the speed of operation and require much less signal power.

Multiple Meaning

Having obtained the possible translations for each word in a sentence, the machine is faced with the problem of selecting the correct meaning from several alternatives. This problem can be attacked in a number of ways.

In technical writing many words have specialized meanings which are used in all texts in a given area of science. For example, *Flügel* in a paper on aeronautical engineering is much more likely to mean "wing" than "grand piano," both of which are given in a general dictionary. The machine could be instructed to select the specialized meaning when the text is known to be in a specialized area (by means of appropriate tags) or special dictionaries could be used.

A number of distinct problems can be recognized in the case of general language. As indicated by the examples, the translation of a word is sometimes based on grammatical considerations, sometimes on the co-occurrence of another word or type of word in the same sentence or clause, and sometimes on the larger context. In all cases, the choice is determined by examining the surrounding words and, according to rules furnished by the linguists, either selecting or eliminating certain alternatives.

The general procedure employed by the machine in selecting the proper meaning can be indicated by an example. For the German sentence given above, a superficial study suggests the following rule for the translation of *zu:* if *zu* is followed by an adjective or adverb, its meaning is "too," but otherwise it is a preposition, and its meaning must be determined by additional analysis. The translating machine can be instructed to examine the tag on the word following *zu* and, if the code designation for an adjective or adverb appears, to select "too" as the meaning.

Not all words present difficulties with multiple meanings, and the mechanical translator can easily locate the trouble-makers in any sentence by counting the alternatives encountered in the dictionary search. Having found a word with several possible meanings, the machine can refer to a list of rules appropriate to this word or its general class of words. This list should be flexible, so that rules can be added or discarded without disrupting the operation of the other rules. The machine can probably be arranged to count the number of times each rule is used and the number of successes scored, so that the effective rules can be applied first and ineffective rules discarded.

The linguistic rules will necessarily be coded and could, in fact, be expressed in algebraic fashion by the techniques of symbolic logic.[7] The resulting algebraic expressions can be simplified by formal procedures and can be converted directly into devices which carry out the selection process. The so-called logic circuits needed in a mechanical translator are employed in conventional arithmetic computers and their design should pose no special problems.

Conclusion

Experiments with word-by-word translation by mechanical means have already been conducted with surprisingly good results, even where no attempt has been made to deal with the problem of multiple meanings. With even a rudimentary set of rules for selecting or eliminating some of the possible meanings, still better results should be obtained. If the linguists can discover the rules, the engineers are ready to build the equipment, given the necessary support. Practical mechanical language translation is a definite possibility for the near future.

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A STUDY OF REACTIONS AT SAND-METAL INTERFACES

(Continued from page 21)

TABLE IV

DIFFRACTION LINES FOR BODY-CENTERED-CUBIC FERRITE

Theoretical and observed position of Bragg reflections with $Fe_{K\alpha 1}$ radiation and $\lambda = 1.93597$ Å

REFLECTION PLANES h,k,l	GRATING SPACINGS "d" (Å)	THEORETICAL BRAGG ANGLES PURE IRON 2θ (deg)	OBSERVED BRAGG ANGLES CAST. NO. 2 2θ (deg)
110	2.02	57.0	57.1
200	1.43	85.0	85.0
211	1 17	112.0	111.6
220	1.01	146.8	145.6

110° to 113° for the (211) planes. The Bragg angle was measured to the nearest 0.01° (2θ) and the lattice constant was calculated.

Results of Precision Lattice Constant Measurements. The lattice constants obtained for Steel Casting No. 1 (silica sand) are given in Table V. The ferrite lattice constant of the cast surface is 0.0011 Å less than that of the interior of the casting.

Table V also lists the lattice constants determined for Casting No. 2. The ferrite lattice constant is 0.0018 Å less for the surface than for the interior. The sample of the surface was mechanically polished and electro-polished to remove 0.010 in. from the cast surface. The ferrite lattice constant at 0.010 in. from the surface was only 0.0003 Å less than for the interior of the casting.

TABLE V

LATTICE CONSTANTS OF EXPERIMENTAL STEEL CASTINGS

CASTING NUMBER	LATTICE CONSTANT (Å)	DIFF. IN LATTICE CONSTANT SURFACE AND INTERIOR (Å)
Steel Casting No. 1		0.0011
Surface	2.8674	
Interior	2.8684	
Steel Casting No. 2		0.0018
Surface	2.8668	
Interior	2.8686	
0.010 in. from surface	2.8683	

The experimental evidence indicates that the reactions at the sand-metal interface cause a distortion of the ferrite crystal lattice so as to decrease the lattice constant.

The relation of the lattice constant to the silicon and manganese content in cast steel is illustrated in Fig. 7. The values were determined experimentally and are listed in Tables VI and VII. Silicon was found to decrease the ferrite lattice constant and manganese to increase the lattice constant as was expected from theoretical considerations.

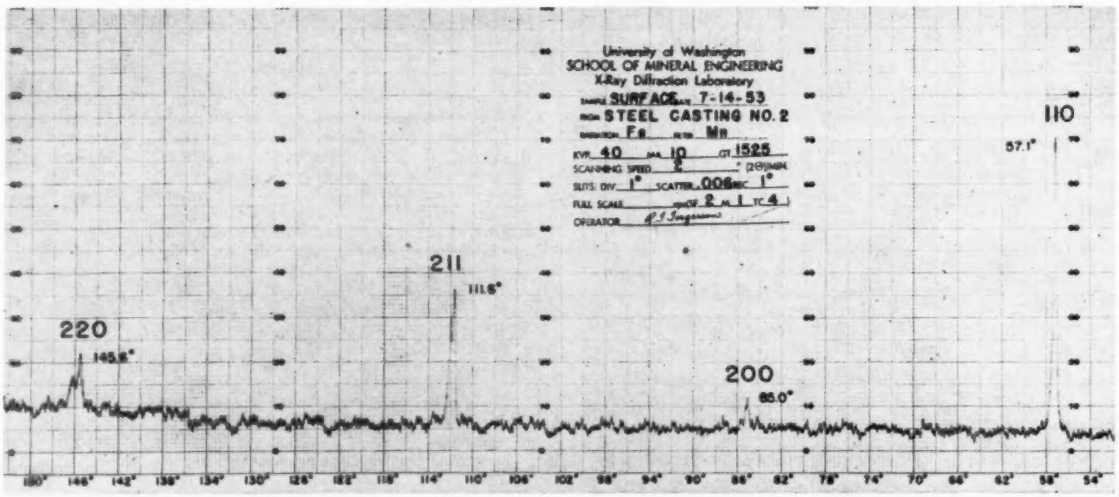

FIG. 6. TYPICAL X-RAY DIFFRACTION PATTERN FOR PRECISION LATTICE CONSTANT MEASUREMENT

TABLE VI

LATTICE CONSTANT AS A FUNCTION OF THE MANGANESE CONTENT OF CAST STEEL

TEST COUPON NUMBER	LATTICE CONSTANT (a_0) (Å)	MANGANESE CONTENT (%)
5	2.8683	0.78
6	2.8692	1.15
7	2.8697	1.87
8	2.8708	2.90

TABLE VII

LATTICE CONSTANT AS A FUNCTION OF THE SILICON CONTENT OF CAST STEEL

TEST COUPON NUMBER	LATTICE CONSTANT (a_0) (Å)	SILICON CONTENT (%)
1	2.8686	0.40
2	2.8658	1.92
3	2.8635	3.74
4	2.8615	4.31

The experimental data apparently indicate that the decrease in lattice constant is due to a possible decrease in the manganese at the surface by the interface reactions. However, insufficient experimental work has been performed to determine if the lattice distortion could be caused by other factors. Stresses and strains due to thermal shock and elastic deformation resulting from differential cooling and contraction may distort the ferrite lattice at the surface. Further work should be directed towards determining the effect of residual stresses and strains on the metallic crystal structure of the cast surface.

Electron Diffraction

An investigation was conducted to determine the possibilities of studying interface reactions with electron diffraction techniques. The advantage of electron diffraction is the very low penetrating power (a few hundred Ångstroms) of the electron beam. This allows a diffraction pattern to be obtained of a very thin layer of a metal surface.

After considerable work with electron diffraction techniques, it became apparent that this method could not be utilized for precision lattice measurements. The poor resolution of the diffraction lines prevented accurate measurement of the Bragg angles.

However, there is still a possibility that electron diffraction techniques can be useful for interface reaction studies. The low penetrating power of the electron beam would be of considerable advantage in identifying the reaction products in the surface skin of steel castings. Electron diffraction can be utilized to determine the crystal structure and identify small amounts of crystalline materials.

Conclusions

The principal chemical and physical changes in the surface layer of steel castings as a result of interface reactions were determined as (1) depletion in carbon, (2) reduction in hardness, and (3) distortion of the crystal lattice of ferrite.

The depletion in the carbon content of the surface layer of steel is due to oxidation at the interface and further diffusion of carbon to the interface. The reduction in hardness in the surface layer of steel is

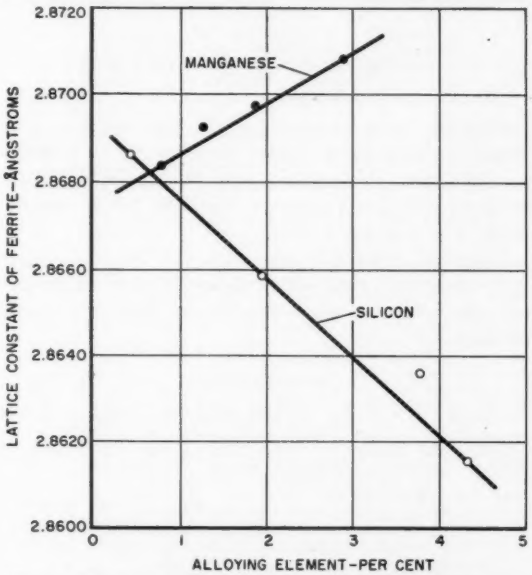

FIG. 7. RELATION OF LATTICE CONSTANT TO SILICON AND MANGANESE CONTENT OF CAST STEEL

caused by a decrease of iron carbide resulting from the carbon depletion. The soft, decarburized layer was 0.030 to 0.060 in. thick for the 10-lb experimental casting. No increase in silicon or manganese content occurred in the surface layer. A decrease in silicon or manganese content could not be established by micro-hardness tests.

The distortion to the crystal lattice of ferrite resulted in a decrease in the lattice constant of ferrite at the surface. This would indicate a decrease in manganese content; however, additional experimental work must be performed to determine if the lattice distortion could be caused by stresses and strains set up by differential cooling and contraction of the casting.

An undesirable reaction occurs between molten steel and straight iron oxide mold wash which limits its use as a mold wash. Alumina has no apparent advantages as a mold wash even though it has no undesirable reactions with molten steel.

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OLIVINE FINES FOR FOUNDRY USE

(Continued from page 7)

obtainable on large castings. In the production of small castings, the processes now in use to provide accurate, smooth surfaces, may be supplemented or replaced by less expensive methods using olivine fines.

Research devoted to the use of olivine fines has succeeded to a point where the by-product may conceivably achieve greater importance than the prime product.

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CORRECTION

The Trend **for April, 1954 was guilty of error in its notice, page 21, regarding the Walker-Ames appointment of Dr. McLachlan. Dr. N. W. McLachlan was appointed Walker-Ames Professor of Electrical Engineering for the fall quarter beginning October, 1954. Dr. McLachlan has been visiting professor (not lecturer) and member of the University Senate at the University of Illinois since September, 1951. The second edition of his book,** ***Complex Variable Theory and Transform Calculus*** **appeared in November, 1953.**

It should be explained however, that the titles, "lecturer" and "professor," as used in the Walker-Ames appointments at the University of Washington, do not denote rank but the length of time such distinguished visitors are on campus.

HOGAN: DESIGN AND USE OF EJECTOR AND DRAFT TUBE FOR THE OZONATION OF WATER

(Continued from page 25)

In summary, the following conclusions have been established:

Equipment:

1. An ejector and properly designed diffuser tube is an excellent device for diffusing air and ozone through water and for maintaining the air in a diffused state.

2. Excellent mixing takes place in the violent eddy currents at the discharge of the ejector and is continued throughout the length of the diffuser tube, because of the action of the diffuser diaphragms. The design of the diffuser tube must be hydraulically balanced to obtain the best mixing.

3. It is desirable to obtain as great a drop in pressure (distributed throughout the length of the diffuser tube) as possible, so that good absorption of the ozone by the water will be procured.

Water Sterilization:

1. Coliform kills may be obtained by the use of ozone.

2. There is a direct relation between the ozone necessary for a bacteriological kill and the flash chlorine demand.

3. A slight advantage is obtained by use of a short detention period for water after it has been treated.

4. No further advantage is gained by allowing the ozonated air to bubble up through the treated water in a detention tank.

5. The bacterial kill is progressive throughout the length of the diffuser tube.

6. A complete coliform kill can be obtained and the treated water still retain a flash chlorine demand. This probably indicates that the ozone acts on living organic matter before acting on dead organic matter.

7. Since good coliform kills have not been obtained from porous plate diffusion, the alternate rarefaction and compression which takes place in the injector system may cause ozone to go into solution more readily by first removing some of the dissolved oxygen.

8. A complete coliform kill was produced by as little as 0.6 ppm of ozone. This places ozone on a more competitive basis with chlorine treatment where the cost of electricity is low.

Patent of 1811: "Specification of the Patent granted to Sarah Guppy, Wife of Samuel Guppy, in the City of Bristol, Merchant; for a Mode of Erecting and Constructing Bridges, and Rail-Roads without Arches or Sterlings, whereby the Danger of being washed away by Floods is Avoided. . . . Fix a row of piles on each side of the river. Pass over the river from the piles several strong metallic chains parallel to each other. Chains may be drawn tight or hung in similar lines, slightly curved. Pieces of timber or iron placed upon the chains are to constitute a platform." *Repertory of Arts, Manuf., and Agri.,* Vol. 19, No. 112, (Sept., 1811), *via* Jakkula: *History of Suspension Bridges.*

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